

AD-A273 034



2

PL-TR-93-2157

SSS-DTR-93-13975

**Development of a Comprehensive Seismic
Yield Estimation System for Underground
Nuclear Explosions**

J. R. Murphy
J. L. Stevens
D. C. O'Neill
B. W. Barker
K. L. McLaughlin
M. E. Marshall
J. N. Jenab

Maxwell Laboratories, Incorporated
S-CUBED Division
P. O. Box 1620
La Jolla, CA 92038-1620

May, 1993

Final Report
17 January 1989 - 15 April 1993

DTIC
ELECTE
NOV 18 1993
S E D

Approved for public release; distribution unlimited



PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA 01731-3010


93-28313




93 11 17 03 0

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Air Force or the U.S. Government.

This technical report has been reviewed and is approved for publication.


JAMES F. LEWKOWICZ
Contract Manager
Solid Earth Geophysics Branch
Earth Sciences Division


JAMES F. LEWKOWICZ
Branch Chief
Solid Earth Geophysics Branch
Earth Sciences Division


DONALD H. ECKHARDT, Director
Earth Sciences Division

This document has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify PL/IMA, 29 Randolph Road, Hanscom AFB MA 01731-3010. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE May, 1993		3. REPORT TYPE AND DATES COVERED Final Report 1/17/89 - 4/15/93
4. TITLE AND SUBTITLE Development of a Comprehensive Seismic Yield Estimation System for Underground Nuclear Explosions			5. FUNDING NUMBERS PE: 62714E PR 9A10 TA DA WU BF Contract# F19628-89-C-0026	
6. AUTHOR(S) J. R. Murphy, J. L. Stevens, D. C. O'Neill, B. W. Barker, K. L. McLaughlin, M. E. Marshall and J. N. Jenab				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Maxwell Laboratories, Inc. S-CUBED Division P. O. Box 1620 La Jolla, CA 92038-1620			8. PERFORMING ORGANIZATION REPORT NUMBER SSS-DTP-93-13975	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Phillips Laboratory 29 Randolph Road Hanscom AFB, MA 01731-3010 Contract Manager: James Lewkowicz/GPEH			10. SPONSORING/MONITORING AGENCY REPORT NUMBER PL-TR-93-2157	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>This report summarizes the research which has been carried out in conjunction with the development of a comprehensive new seismic yield estimation system (YES) for underground nuclear explosions. Specifically, it provides a detailed description of the final version of YES which has been implemented at the ARPA Center for Seismic Studies (CSS) to estimate seismic yields of explosions at the Shagan River and Novaya Zemlya test sites of the former Soviet Union. In its current configuration, the YES encompasses a database of more than 15,000 digital seismograms recorded at stations of the USAEDS, GDSN, CDSN and IRIS networks from explosions at these two test sites. For both test areas, information regarding the explosion source environment is presented to the analyst in the context of SPOTTM satellite images of the sites, together with associated surface and subsurface geologic information and DMA topographic data.</p>				
14. SUBJECT TERMS Nuclear Explosions Yield Estimation Seismic			Software System Shagan River Novaya Zemlya	15. NUMBER OF PAGES 128
			X Window YES CSS	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR	

Motif is a trademark of the Open Software Foundation, Inc.

X Window System is a trademark of the Massachusetts Institute of Technology.

Sun SPARCStation is a trademark of Sun Microsystems, Inc.

SPOT data are copyrighted by CNES (1986,1987).

UNIX is a registered trademark of AT&T Bell Laboratories.

FrameMaker is a registered trademark of Frame Technology Corporation.

Accession For	
NTIS	<input checked="checked" type="checkbox"/>
DTIC	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC QUALITY INSPECTED 8

Table of Contents

List of Illustrations.....	v
Introduction	1
Overview of Selected YES Capabilities	4
Summary	31
References	33
Appendix A: Requirements and Startup Instructions	35
Hardware Requirements	35
Software Requirements	35
Startup Instructions	35
Shutdown Instructions	36
FrameMaker Instructions.....	37
Appendix B: Script For Sample Session	38
Appendix C: Reference	49
Introduction	49
Main Menu	51
Satellite Image	55
World Map	65
Analyst Station	67
Magnitude Measurement	73
Yield Estimation	89
CORRTEX Yield.....	93
Statistical Summary	94
Spreadsheet	99
Event Summary	102
Event Report	103
Appendix D: Dependencies between YES modules	107
Appendix E: Adding Data to YES.....	108

List of Illustrations

Figure 1:	Main menu structure for YES.....	4
Figure 2:	Illustration of pulldown access to individual menus	5
Figure 3:	SPOT satellite image of the Shagan River test site with superimposed locations of the historical explosions (squares) and current event (diamond)	6
Figure 4:	Full resolution SPOT satellite image of the region surrounding the Shagan River cratering explosion of 15 January 1965	7
Figure 5:	Illustration of interactive modification of brightness and contrast in SPOT satellite image display	8
Figure 6:	SPOT satellite image of the Shagan River test site with superimposed surface geologic map and current event location.....	8
Figure 7:	Color-coded representation of DMA topographic data for the Shagan River test site with super- imposed topographic contours and current event location.....	9
Figure 8:	Vertical subsurface section through the current event shotpoint along the interactively selected line shown on the SPOT image insert	10
Figure 9:	Color-coded representation of depth to the top of the granite surface beneath the Shagan River test site with superimposed depth contours and current event location.....	10
Figure 10:	World Map projections ($\Delta < 100^\circ$) showing locations of stations for which digital teleseismic P (left) and L_g (right) data are available for the current event	11
Figure 11:	Analyst station display of vertical-component L_g signals for the current event.....	12
Figure 12:	Magnitude Measurement menu	13

Figure 13:	Analyst station display of selected vertical-component teleseismic P wave signals for the current event	14
Figure 14:	Example of the specification and subsequent application of a bandpass filter to the data of Figure 13	15
Figure 15:	SPOT locations of Shagan River explosions recorded at station KONO in Norway. The diamond symbols denote those events selected for comparative analysis.....	16
Figure 16:	Comparison of the P wave signal recorded at the station KONO from the current event (top and red) with the signals recorded at that station from the selected events of Figure 15.....	16
Figure 17:	Illustration of the interactive determination of the amplitude and period values used to define single station m_b values.....	17
Figure 18:	Comparison of individual station and network-averaged m_b magnitudes determined for the current event.....	18
Figure 19:	Comparison of individual station and network-averaged ML_g magnitudes determined for the current event	18
Figure 20:	Comparison of the observed value of m_b-ML_g (NORSAR) for the current event with the contours representing observed variation of that parameter for previous events	19
Figure 21:	Analyst station display of selected long-period Rayleigh wave signals for the current event.....	20
Figure 22:	Example of the specification and subsequent application of the instrument response normalization feature to the data of Figure 21	20
Figure 23:	Menu options for the estimation of network-averaged P wave spectra	21
Figure 24:	Comparison of normalized observed and best-fitting theoretical network-averaged P wave spectra for the current event	22

Figure 25:	Comparison of the inferred surface wave moment tensor solution for the current event with the corresponding path normalized, observed Rayleigh (left) and Love (right) wave amplitude data.....	22
Figure 26:	Comparison of the surface wave moment tensor solution for the current event (yellow and light blue concentric circles) with those for nearby Shagan River explosions (red and dark blue concentric circles) and with the surface geologic map of the area	23
Figure 27:	Menu and sample output for the unified yield estimation module.....	24
Figure 28:	Comparison of unified yield estimates (W) and associated uncertainties (F) obtained with (top) and without (bottom) the surface wave moment tensor magnitude.....	25
Figure 29:	Statistical assessment menu	26
Figure 30:	Comparison of the results of three different tests of seismic compliance of the current event with the 150 kt threshold of the TTBT	27
Figure 31:	Compliance test results (Test 1) for the scenario in which the current event data were observed from an explosion below the water table at NTS	27
Figure 32:	Spreadsheet summary comparison of seismic yield estimates for the current event (09/14/88) with those obtained for selected previous Shagan River explosions	28
Figure 33:	Spreadsheet summary illustrating the results of interactively modifying the designated magnitude/ yield relations.....	29
Figure 34:	Summary of analysis results for the selected event	30

1

Introduction

Over the past several years S-CUBED, under ARPA support, has been developing a comprehensive new seismic yield estimation system for underground nuclear explosions. The principal objective of this program has been to implement a flexible, interactive software system in which yield estimates based on a wide variety of different seismic magnitude measurements can be efficiently determined, merged with all available information regarding the test location under consideration and statistically combined to obtain both a unified seismic estimate of explosion yield and quantitative measures of the uncertainty in that estimate. A system designed to achieve the above objective, designated the Yield Estimation System (YES), has now been implemented in a Sun color workstation (SPARCStation) environment at the ARPA Center for Seismic Studies (CSS). This document provides a user's guide which is applicable to the current version of that system. A comprehensive overview of the system software design and technical specifications was provided previously in a report by Murphy *et al.* (1991).

In its current configuration, the system is applicable to underground nuclear explosions at the Soviet Shagan River and Novaya Zemlya test sites and encompasses a database of more than 15,000 digital seismograms recorded at stations of the USAEDS, GDSN, CDSN and IRIS networks from explosions at these two sites. For both test areas, information regarding the explosion source environment is presented to the analyst in the context of SPOTTM satellite images of the sites, together with associated surface and subsurface geologic information and DMA topographic data. The on-line database for YES also contains a wide variety of tabular information, including complete event and station location files containing both classified and unclassified locations, standard travel-time tables for the important phases (Herrin *et al.*, 1968), propagation path and station corrections for use in magnitude determinations and a comprehensive instrument

response database. The instrument database is a compilation of information collected from the USGS, AFTAC, IRIS and others which details the characteristics of the recording instruments as a function of station, channel and date. There are currently 750 different response histories in this section of the database. The portion of this seismic database associated with Shagan River explosions has recently been transferred to CD-ROM and distributed widely throughout the ARPA/PL seismic research community.

The user interface to the system has been designed to be completely menu-driven and mouse-activated and requires no keyboard entry by the operator once the system has been accessed. This graphical user interface has been built using the X Window system. X was designed specifically to allow hardware independence, to foster ease in porting applications to machines other than those for which they were developed, and to permit running of applications on one computer while displaying their output on another, even if the computers are of different manufacture. YES was designed and implemented on Sun SPARC computers (e.g., SPARCStations), but transfer to any other system that supports X and UNIX could be accomplished easily. The X interface has been written using the X toolkit. The X toolkit enforces an object-oriented approach to programming by combining the windows and the operations on the windows into "widgets." YES uses several widget sets including the Motif widget set from the Open Software Foundation, the X widget set from Hewlett Packard, the Athena widget set from MIT, graphics widgets written by Teledyne-Geotech and SAIC, and special purpose widgets for YES written by S-CUBED.

YES consists of a hierarchy of programs. At the top level is a master program whose primary function is to start the other analysis programs. The top level program allows the user to select the test site, event and seismic phase to be processed, as well as the analysis tools to apply to the seismic data corresponding to that selection. It then starts the appropriate analysis programs with the proper initialization values. All the required software has been written in either the C or FORTRAN programming languages. C was chosen because programmer's calls to the X Window System procedures are in C, and because C is well-suited to the design of complex systems with a variety of data structures. FORTRAN was used

because it is optimal for certain types of computational analysis, and because its use permitted the inclusion of many previously existing analysis tools into YES. As a result, the top level programs, interactive modules, database interface, and graphics routines are written in C, and, when appropriate, these routines call FORTRAN subroutines.

This document provides a user's guide and reference manual for the operation of the YES system. In Section II, the capabilities and functionality of the system are graphically illustrated through displays of the screens encountered by an analyst in a typical processing session for a selected explosion (i.e., the Soviet JVE explosion of 14 September 1988). This is followed in Section III by a brief summary of the development of the YES system. A detailed script of the operator actions required to reproduce this sample session is provided in Appendix B. This is preceded in Appendix A by an overview of the software and hardware required to implement YES, as well as detailed start-up instructions for the system. Appendix C provides a complete description of all the currently available system options, including information regarding their access and application from the menus contained in the individual analysis modules. This is followed in Appendix D by a top level schematic diagram of the main modules of the system and their interdependencies. Finally, Appendix E provides a description of an off-line module which has been implemented to permit the analyst to add new events and seismic data to the system.

2

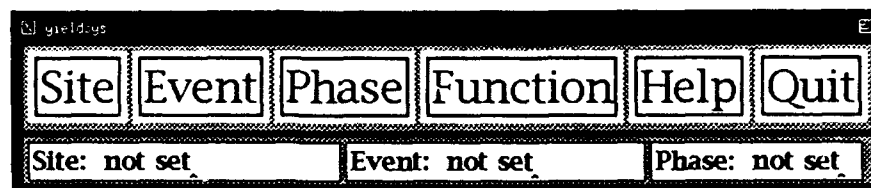
Overview of Selected YES Capabilities

In this section, some of the capabilities and functionality of the YES system will be graphically illustrated through displays of the screens encountered by an analyst in a typical processing session for a selected explosion. For this example, the unclassified data from the Soviet JVE explosion of 14 September 1988 will be analyzed and used to illustrate various features of the system. A detailed script of the operator actions required to reproduce this sample session is provided in Appendix B. This is followed in Appendix C by a complete description of all the system options which are available in the current version.

Main Menu

As has been noted previously, a distinguishing characteristic of the YES is that it is completely menu-driven and mouse-activated and requires no keyboard entry by the user. The top level menu providing access to the system is shown in Figure 1. It consists of six buttons which can be used to initiate (SITE, EVENT, PHASE, FUNCTION) or terminate (QUIT) action within the system or to view on-line information regarding the operating characteristics and parameters of the system (HELP). Choosing any of these buttons causes a series of pulldown menus to be activated as illustrated in Figure 2. In this example, the SITE button has been activated to select the Soviet Shagan River (Balapan) test site, and the EVENT button has been activated to select the JVE explosion which was detonated at that test site on 14 September 1988. Once the test site and event have been selected, the remaining analyst interaction with the system is initiated through the PHASE and FUNCTION buttons. The PHASE button provides the analyst with the capability to choose from among the six different seismic phases listed in Figure 2 for which digital waveform data are currently available on the system. The FUNCTION button provides access to the ten

Figure 1.
Main menu
structure
for YES.

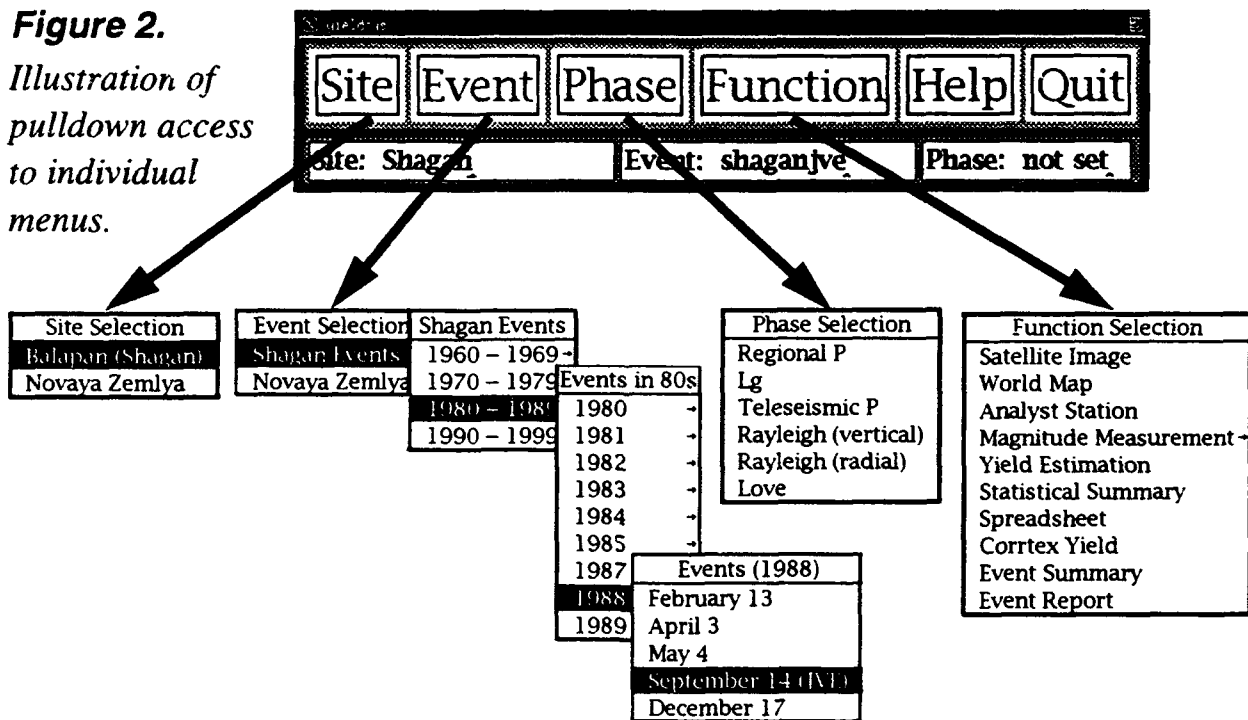


principal computational and analysis modules which permit the analyst to:

- view the seismic data within the context of the available information regarding the specific test location under investigation (*Satellite Image, World Map*)
- interact with the recorded seismic data to process it and extract the various magnitude measures of interest (*Analyst Station, Magnitude Measurement*)
- formally combine the seismic measures of source size to obtain an optimum measure of explosion yield and quantitative measures of the uncertainty in that estimate (*Yield Estimation, CORRTEx*)

Figure 2.

*Illustration of
pulldown access
to individual
menus.*

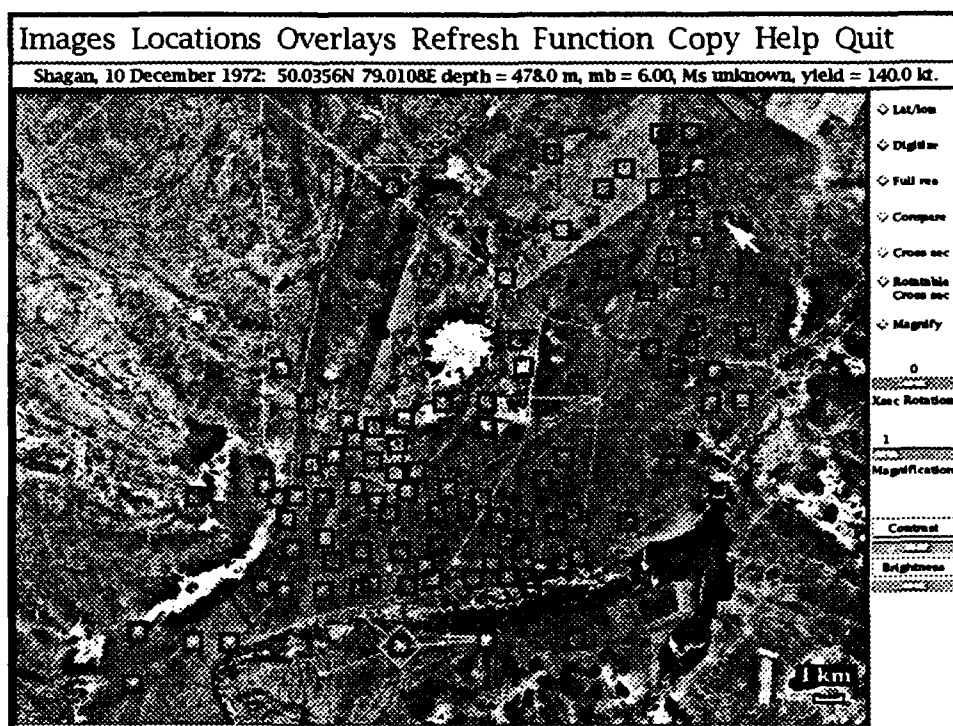


- statistically assess the results with respect to any existing treaty thresholds or other yield levels of particular interest (*Statistical Summary, Spreadsheet*)
- document the results obtained by applying the system to the data recorded from the selected explosions (*Event Summary, Event Report*).

Satellite Image

Having specified a test site and a particular explosion (in this case the JVE event), a typical analysis sequence would begin with the selection of the *Satellite Image* option from the FUNCTION menu, which brings to the screen the SPOT satellite image display of the Shagan River test site shown in Figure 3. In this initial display of the test site information interface, the locations of previous explosions at this site are shown as color-coded square overlays, with the current event highlighted by a yellow diamond. In this case, the different colors are used to differentiate those explosions about which the Soviets have published data in the open literature (blue) from those for which only seismic information is available (red). It is important to note that this is not merely a static display, but that in fact the image and the overlays to it are formally tied to an extensive on-line database of supplementary information. Thus, for example, in this figure the operator has clicked on one of the blue squares (arrow), which has initiated a process by which available information about that event has been extracted from the database and displayed on the information line below the menu buttons, indicating that this explosion was detonated at Shagan on 10 December 1972 at the specified latitude and longitude and that Bocharov *et al.* (1989) have reported the depth as 478 m and the yield as 140 kt.

Figure 3.
SPOT satellite image of the Shagan River test site with superimposed locations of the historical explosions (squares) and current event (diamond).



Full res

For purposes of display, the satellite image shown in Figure 3 has been compressed to an effective resolution of about 30 m so that the entire test site can be viewed on a single screen. However, the data corresponding to the full 10 m resolution of the SPOT image can also be viewed by activating the appropriate button (*Full res*) on the right hand margin of this display and simply pointing with the mouse to any location on the image. For example, Figure 4 shows the full resolution sub-image corresponding to the location of the cratering explosion of 15 January 1965 which dammed the Shagan River, producing the prominent lake in the southeast quadrant of Figure 3. Another feature provided by this image display module is the capability to interactively adjust the contrast and brightness using the slider bars located at the bottom of the right hand menu margin. Figure 5 illustrates this feature by way of a comparison of the nominal display (left) with that resulting from interactively reversing the contrast and decreasing the brightness (right) by repositioning these sliders with the mouse. It can be seen that different features are emphasized in these two displays, which facilitates analyst identification of both geologic and man-made features.

Surface Geology and Topography

In addition to the event locations, a number of geologic and topographic databases have been registered to this SPOT image and are available for display from the OVERLAYS and IMAGES menus. For example, Figure 6 shows the overlay of Leith's (1989) color-coded, surface geologic

Figure 4.
*Full resolution
SPOT satellite
image of the
region sur-
rounding the
Shagan River
cratering
explosion of 15
January 1965.*

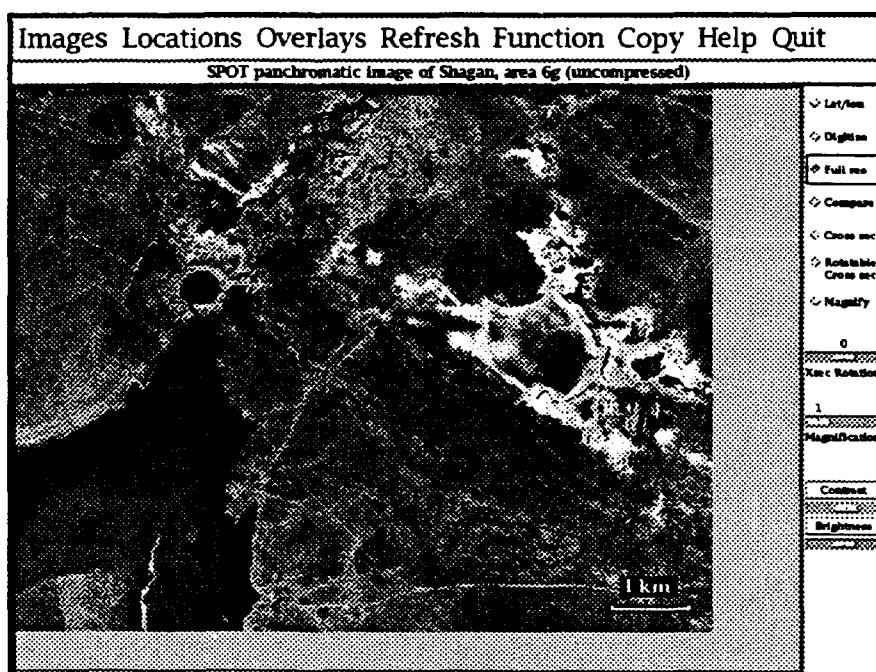


Figure 5.

Illustration of interactive modification of brightness and contrast in SPOT satellite image display.

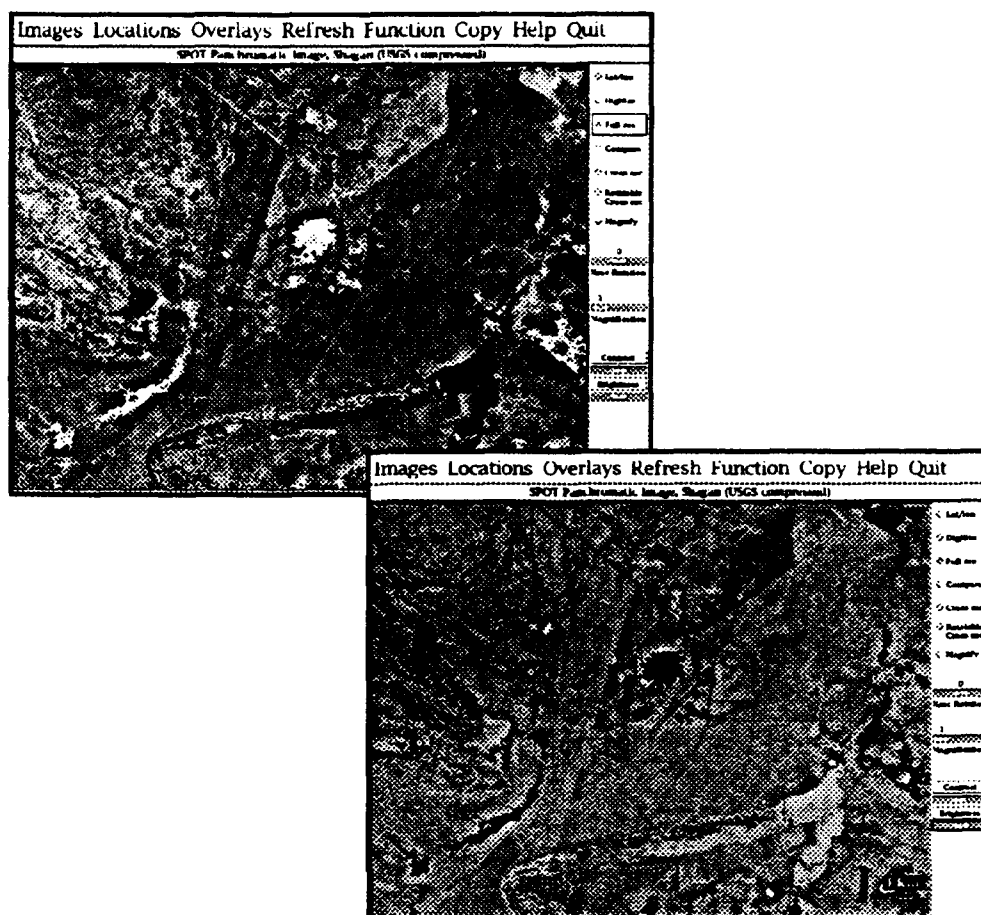
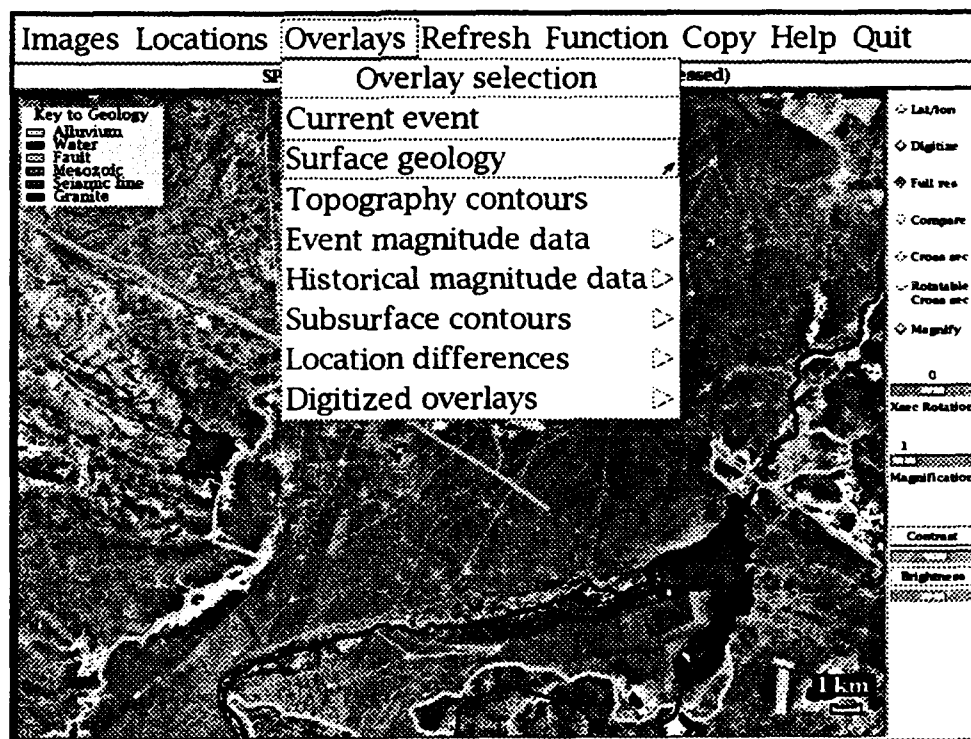


Figure 6.

SPOT satellite image of the Shagan River test site with superimposed surface geologic map and current event location.



map of the area, where the location of the current event (square) is shown in the context of the various exposed geologic units and the trace of the prominent Chinrau fault which intersects this portion of the test site. The Defense Mapping Agency's topographic database for the area is displayed in color-coded image form in Figure 7 together with overlays of the corresponding topography contours and current event location selected from the OVERLAYS menu.

Cross Section

The variation of surface topography, as well as subsurface geology to a depth of about 1 km, along any specified line across the image can be accessed using the cross-section button (*Cross sec*) on the right hand margin of the image display. This feature is illustrated in Figure 8 where the left hand panel shows the line selected by the analyst by pointing with the mouse to two arbitrary points on the SPOT image and the right hand panel shows the resulting vertical section through that line which was automatically produced by the system, together with the locations and approximate depths of penetration of explosion emplacement holes encountered along that line.

Figure 7.
Color-coded representation of DMA topographic data for the Shagan River test site with superimposed topographic contours and current event location.

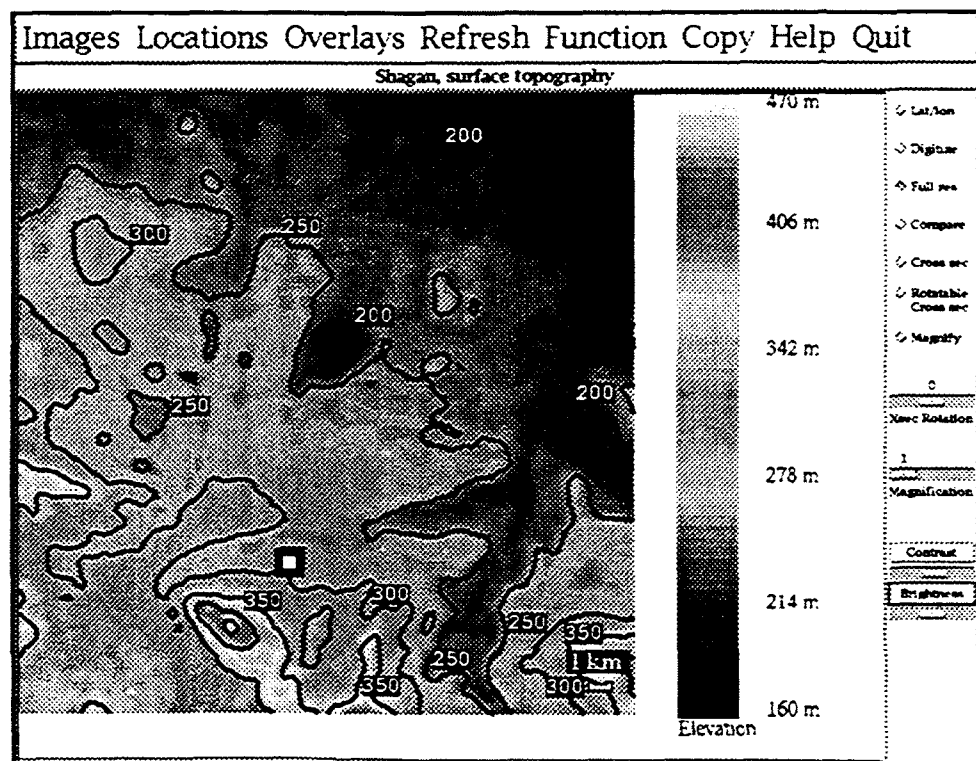
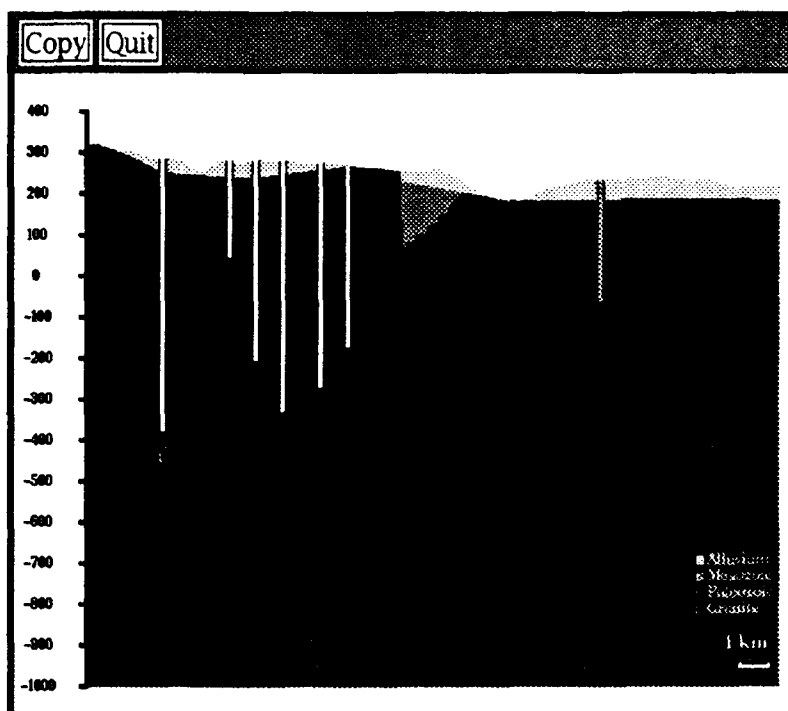
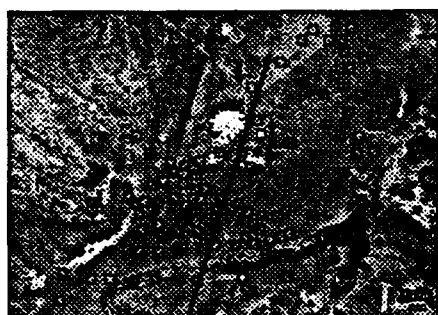


Figure 8.

Vertical subsurface section through the current event shot-point along the interactively selected line shown on the SPOT image insert.

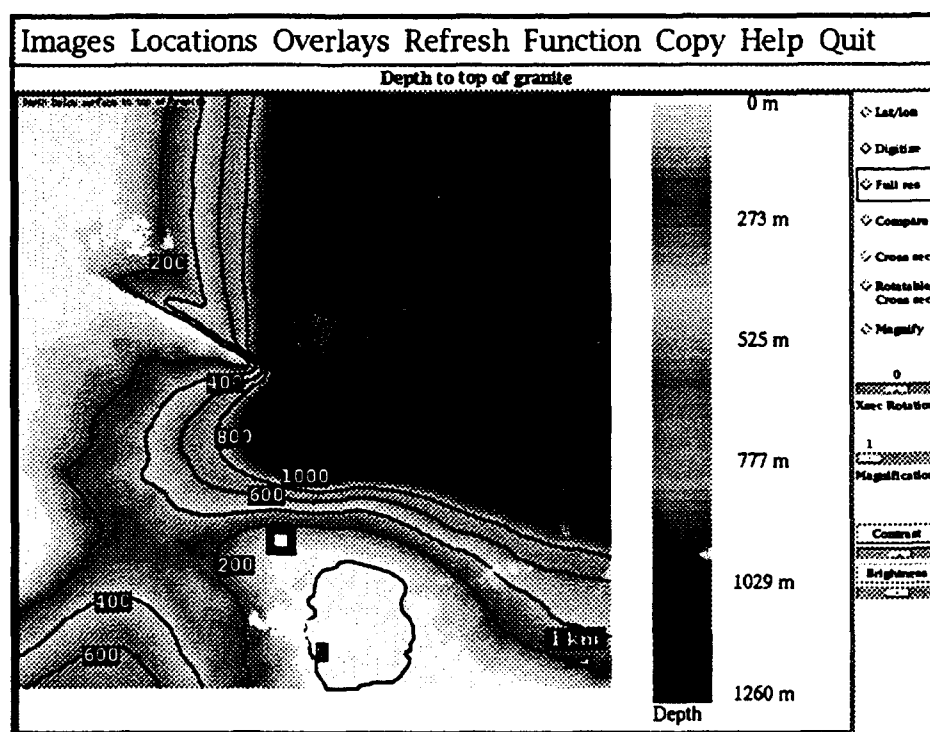


Depth-to-Granite

As with the surface topography, the variation in the depth to any selected geologic interface can also be exhibited in image form, as illustrated for the granite surface in Figure 9 where, once again, the corresponding depth contours and location of the current event have been overlaid for reference purposes. It is immediately evident from this presentation that,

Figure 9.

Color-coded representation of depth to the top of the granite surface beneath the Shagan River test site with superimposed depth contours and current event location.



World Map

Figure 10.

Phase Station Refresh Help Copy Quit

World map, 100 degrees radius about Balapan

Phase P

Phase Station Refresh Help Copy Quit

World map, 100 degrees radius about Balapan

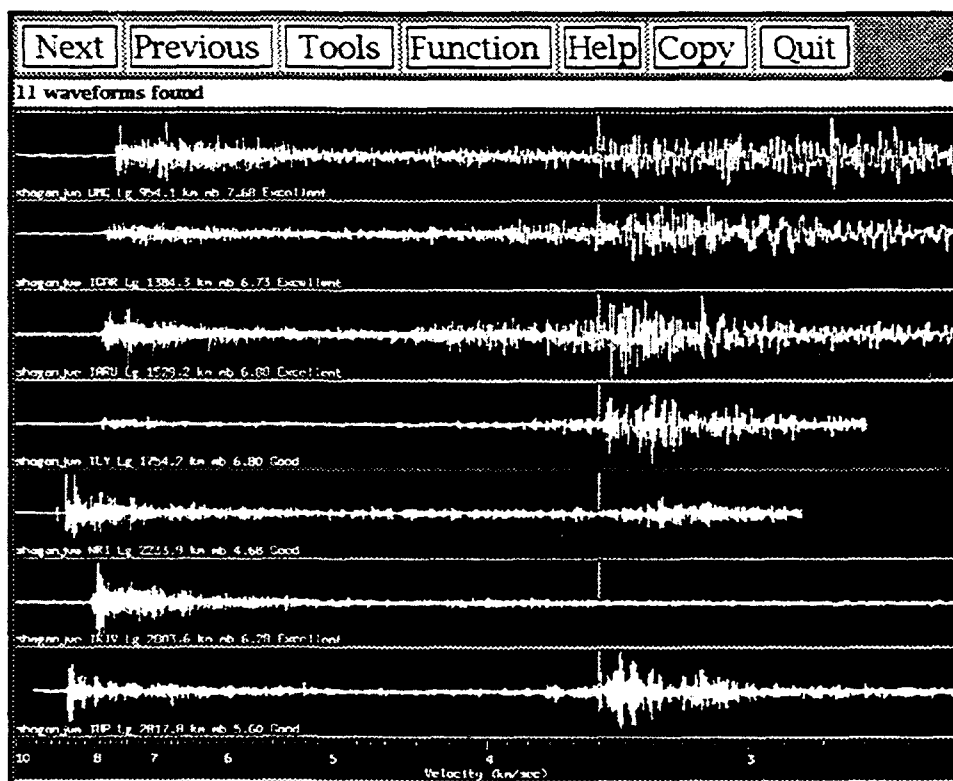
Phase I.g

the propagation path followed by the main energy groups between these two points.

Analyst Station and Magnitude Measure- ment

The seismic data themselves can be accessed by returning to the main menu (Figure 2) and sequentially selecting a seismic phase from the PHASE menu and *Analyst Station* from the FUNCTION menu. Thus, for example, specifying the phase L_g in this manner automatically initiates a process by which the L_g recordings from the JVE explosion are extracted from the on-line database of digital waveform data and displayed on the screen in the format shown in Figure 11. In this and subsequent seismogram displays, the stations are ordered by increasing epicentral distance and, for the L_g and surface waves, the data are plotted as a function of group velocity. It can be seen in this figure that the traces are marked by a vertical line at a group velocity of 3.5 km/sec, indicating the nominal expected onset time of the L_g phase. This display permits the analyst to quickly assess the quality of the data and identify any prominent characteristics. Thus, for example, it can be seen from Figure 11 that the L_g signals are relatively weak at the IRIS station KIV (IKIV) and at NORSAR (N01A0), consistent with the expected effects of propagation across the Caspian Sea (KIV) and along the complex, far-regional path to Norway.

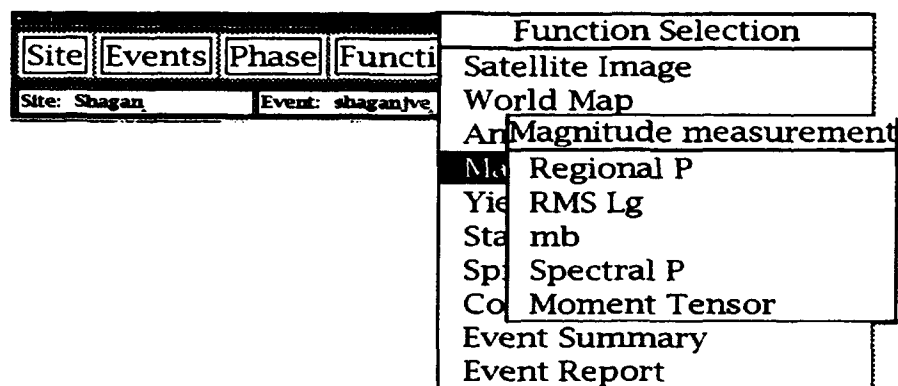
Figure 11.
*Analyst sta-
tion display
of vertical-
component L_g
signals for
the current
event.*



RMS L_g Startup

Having verified that the available L_g data are suitable for further processing, the analyst can proceed to magnitude estimation by selecting the *Magnitude Measurement* option from the FUNCTION menu as illustrated in Figure 12. Selecting RMS L_g from this list of five currently available magnitude measures initiates a series of operations by which the L_g waveforms recorded from the JVE event are automatically processed using algorithms described by Ringdal (1983) to obtain single-station and network-averaged measures of the L_g magnitude, M_{Lg} . Since this processing

Figure 12.
Magnitude Measurement menu.



takes some time to accomplish, it is run in the background, thereby permitting the analyst to move on to other tasks while it is being completed. In the present example, the analyst has selected *Teleseismic P* from the PHASE menu and *Analyst Station* from the FUNCTION menu, resulting in the waveform display shown in Figure 13. The P wave seismograms are plotted here as a function of reduced time, extending from 10 seconds before to 15 seconds after the signal onset time which is denoted by the vertical line segments. Generally, there are more recordings than can be displayed on a single screen in this format and, in such cases, the analyst can readily page forward and backward through these multiple screens using the NEXT and PREVIOUS menu buttons at the top of the analyst station display.

Tools

An extensive set of signal processing and analysis capabilities has been assembled within the analyst station module, as indicated by the TOOLS menu display in Figure 13. These tools permit the analyst to:

- redefine arrival times (*Pick Arrival*),
- assign waveform quality (*Set Quality*),
- measure amplitudes and periods (*Expand, m_b*),

- filter the data (*Demean/detrend, Filter*),
- normalize to a common instrument response (*New instrument*),
- compare a selected waveform with waveforms recorded at that station from previous explosions (*Compare, Clone*).

Filter

Thus, for example, it can be seen from Figure 13 that the P wave signal recorded at station MAJO in Japan (bottom trace) is obscured by microseismic noise lying outside the signal passband. Selecting *Filter* from the TOOLS menu causes the interactive filter interface to be displayed as shown in Figure 14, where the analyst has used the mouse to adjust the slider bars to define low and high frequency cutoffs of 0.5 and 5.0 Hz, respectively, and to specify a second order roll-off outside that band by setting the corresponding pole numbers to 2. Subsequent selection of any trace with the mouse causes this filter to be automatically applied and the result displayed, as shown here for station MAJO.

Compare

Application of the *Compare* function from the TOOLS menu provides another illustration of the powerful capability for interactive analysis which is available in the analyst station. For example, by sequentially

Figure 13.
Analyst station display of selected vertical-component teleseismic P wave signals for the current event.

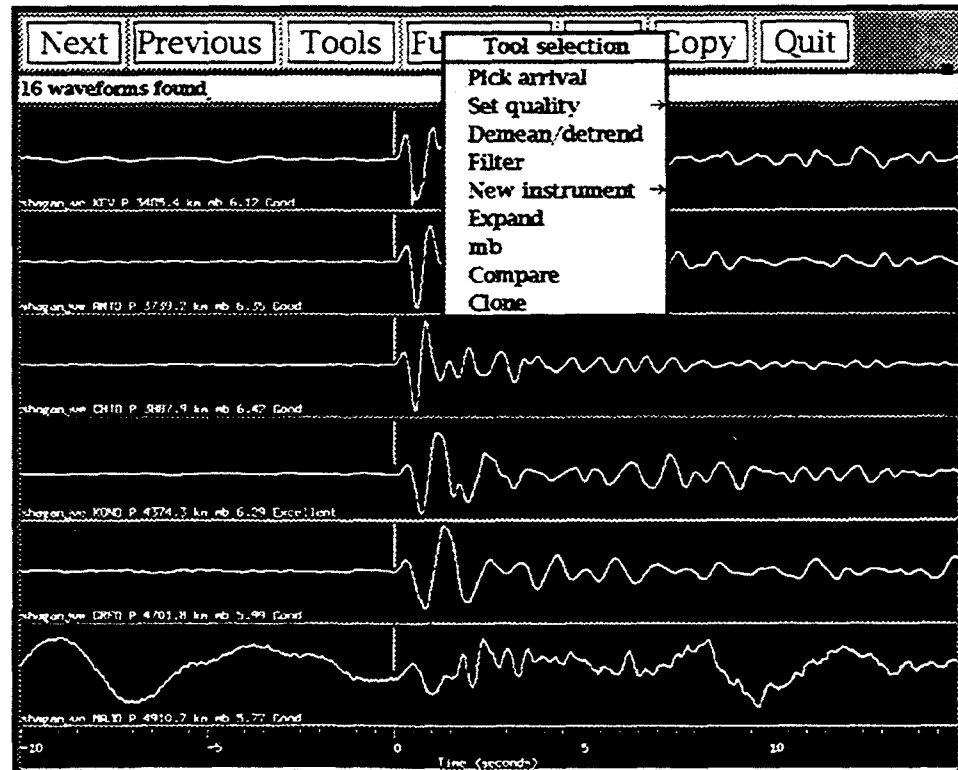
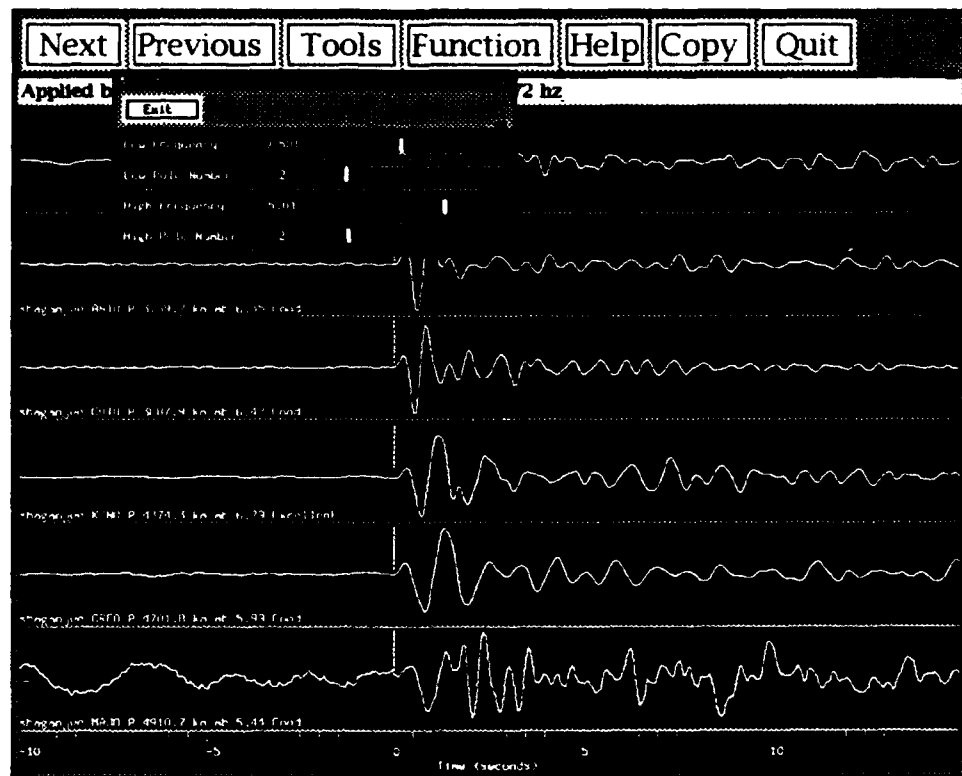


Figure 14.
Example of
the specifi-
cation and
subsequent
application
of a band-
pass filter to
the data of
Figure 13.



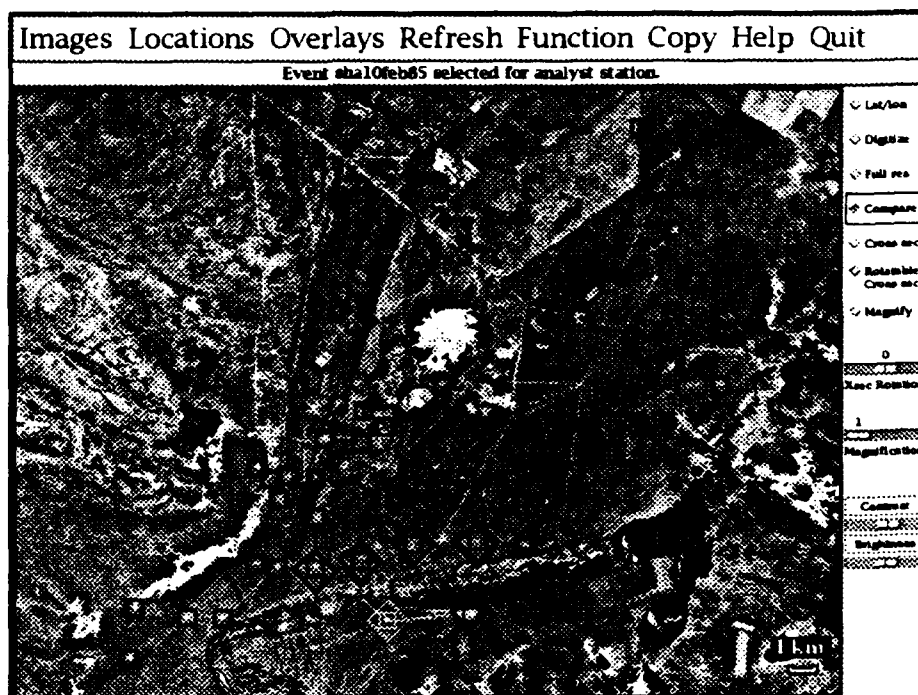
selecting this function and the station KONO waveform from Figure 14, a search through the database is automatically initiated to identify all other available P waveforms recorded at that station from previous Shagan River explosions. Generally, not all of the explosions identified by this search are of equal importance for comparative purposes and selection of a meaningful subset is facilitated by examining their locations in the context of the SPOT image test site information interface, as indicated in Figure 15. Using this interface, the analyst can interactively select specific events with the mouse, as indicated here by the diamond overlays, on the basis of proximity to the current event or some other criterion, and display the corresponding P waveforms in a time expanded analyst station mode such as that of Figure 16. Here the current JVE event recording is shown at the top of the figure and the waveforms from the selected comparison events are displayed beneath it in the order in which they were selected.

Clone

Also illustrated in Figure 16 is the use of the *Clone* feature from the TOOLS menu which permits the operator to select any trace on the screen with the mouse (in this case the JVE recording), create a color-coded (red)

Figure 15.

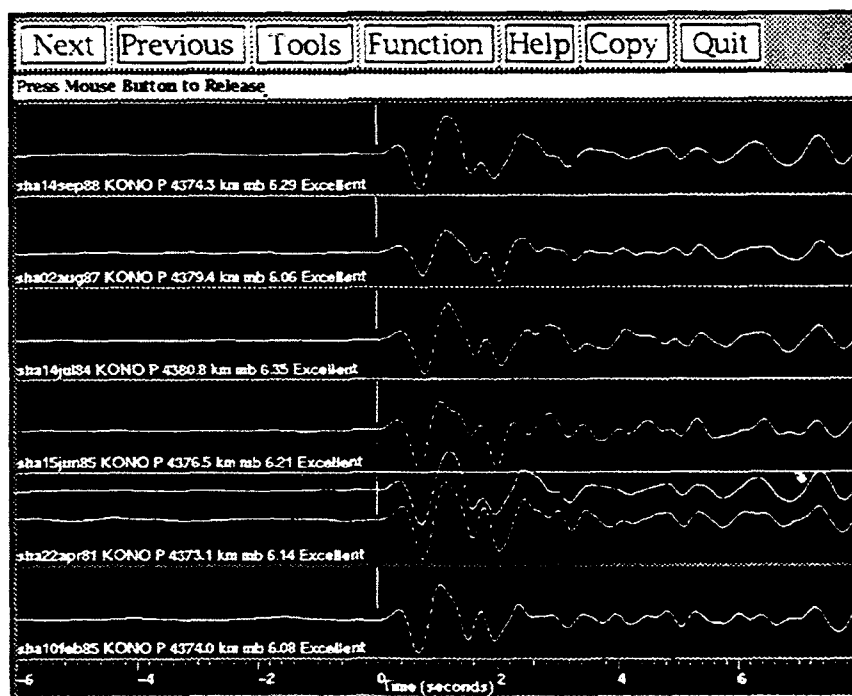
SPOT locations of Shagan River explosions recorded at station KONO in Norway. The diamond symbols denote those events selected for comparative analysis.



copy and drag it to any other location on the screen to conduct detailed waveform comparisons. This capability permits the analyst to quickly assess the consistency of the current observation with past experience and, in this case, to conclude that the JVE recording at KONO is quite consistent with previous observations at that station from other explosions located in that area of the test site.

Figure 16.

Comparison of the P wave signal recorded at the station KONO from the current event (top and red) with the signals recorded at that station from the selected events of Figure 15.



Expand and m_b

Once the initial waveform review has been completed, the analyst can proceed to magnitude estimation using the *Expand* and m_b functions from the TOOLS menu. By sequentially selecting *Expand* and any waveform from the analyst station display, a magnified reproduction of that waveform is produced as shown in Figure 17. Then, by employing the m_b function, the mouse can be used to position a rectangle so as to define the peak-to-peak amplitude and half period of the selected cycle of motion as shown in this figure. After this process has been repeated for each usable trace, the resulting amplitudes are input to the m_b estimation module using the *Magnitude Measurement* menu of Figure 12 where they are converted to ground motion, corrected for epicentral distance and station effects and logarithmically averaged to obtain a network-averaged m_b value and associated uncertainty. The resulting individual station m_b values for the current JVE explosion are displayed in Figure 18, together with the estimated network-averaged value of 6.012. This display module also provides the capability for the analyst to interactively eliminate questionable data points and then to recalculate the network average using the ADD/DELETE and RECALC menu buttons shown at the top of the figure. This process can be continued until a final stable m_b estimate is obtained, at which time it is written to the database using the designated SAVE menu button.

Figure 17.
*Illustration of
the interactive
determination
of the ampli-
tude and
period values
used to define
single station
 m_b values.*

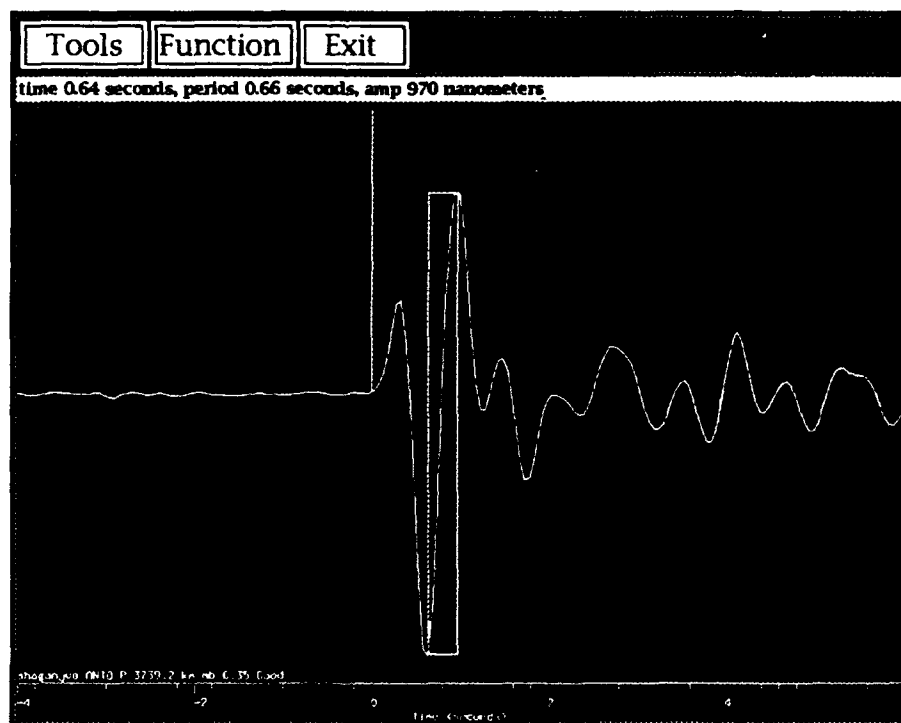
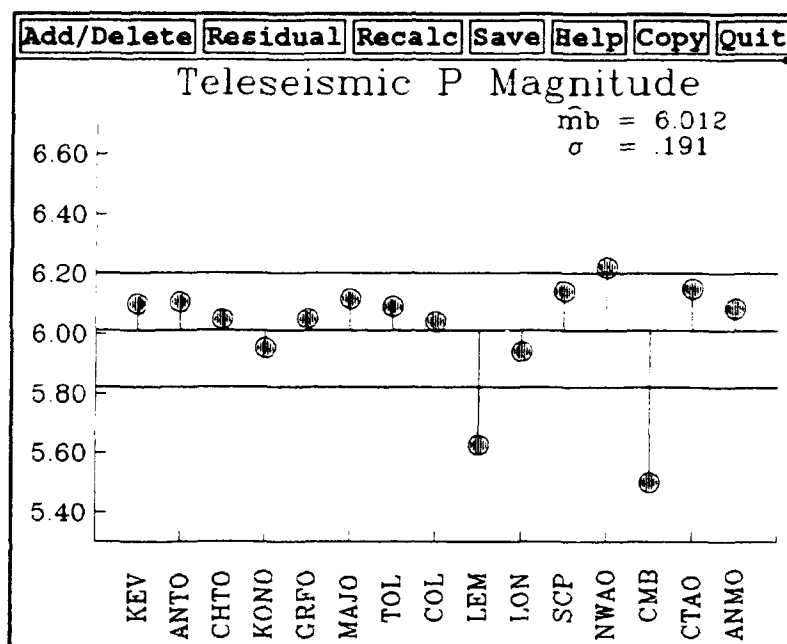


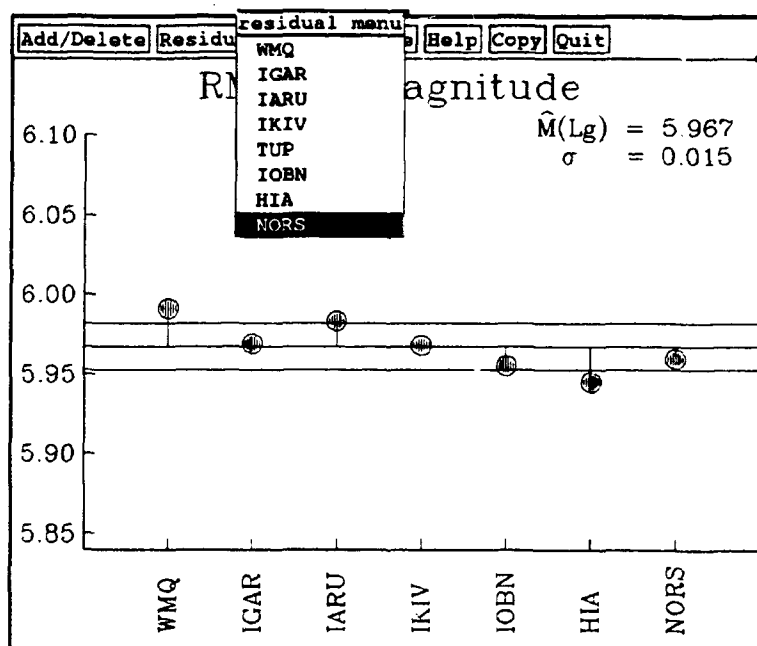
Figure 18.
Comparison of
individual sta-
tion and net-
work-averaged
 m_b magnitudes
determined for
the current
event.



RMS L_g

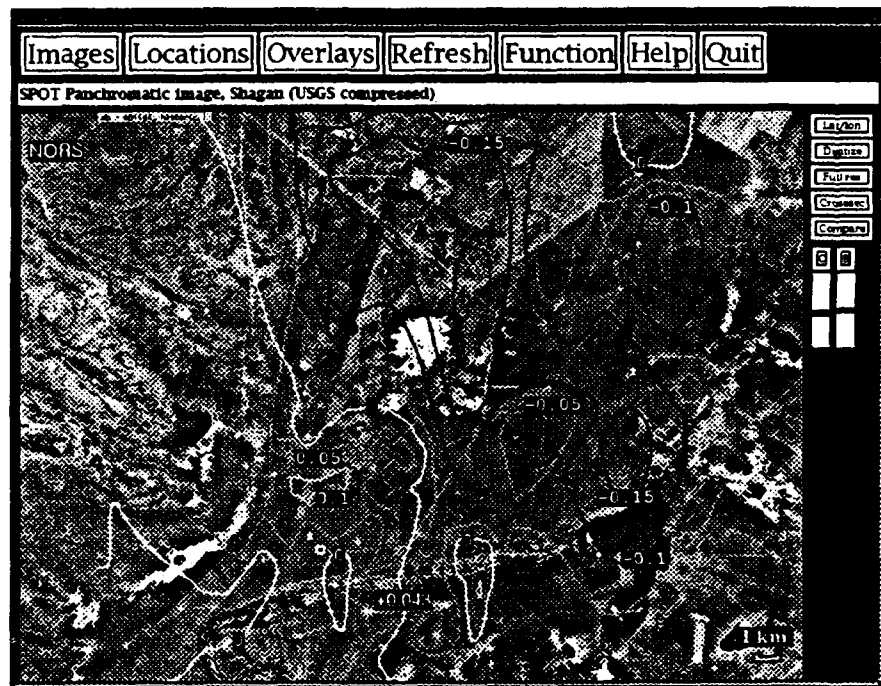
Note from Figure 18 that at this point the system has notified the analyst that the RMS L_g magnitude estimation has been completed, as indicated by the icon in the upper left hand corner of this display. Selecting this icon with the mouse produces the display of individual station and network-averaged M_{Lg} values shown in Figure 19. It can be seen from this figure that the estimated network-averaged M_{Lg} value of 5.967 is somewhat lower than the corresponding m_b value of 6.012 of Figure 18, and it would be natural for the analyst to question whether there is any significance to

Figure 19.
Comparison of
individual sta-
tion and network-
averaged M_{Lg}
magnitudes
determined for
the current event.



this difference. This issue can be addressed by selecting a representative station (e.g., NORS) from the RESIDUAL menu on this display and returning to the SPOT image test site information interface to overlay the quantity $m_b - M_{Lg}(\text{NORS})$ at the current event location as in Figure 20, where contours of this quantity derived from results of previous explosions have also been overlaid for reference purposes. It can be seen from this display that while this magnitude difference is typically negative in the northeast quadrant of the test site (by as much as 0.15 magnitude units), it is generally positive in the vicinity of the current JVE event location, with an average value close to the observed value of 0.043. Thus, this capability permits the analyst to quickly conclude that the current result is entirely consistent with previous experience in this area of the test site.

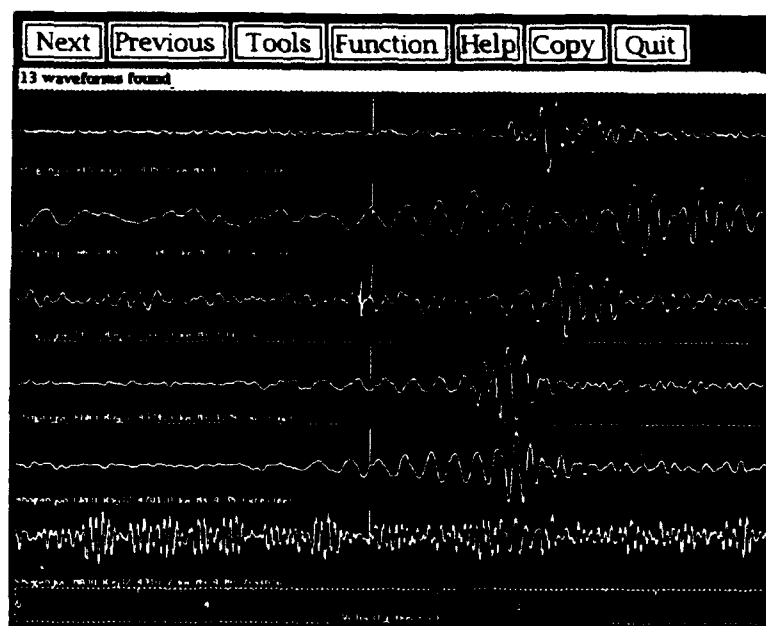
Figure 20.
Comparison of the observed value of $m_b - M_{Lg}(\text{NOR-SAR})$ for the current event with the contours representing observed variation of that parameter for previous events.



New instrument

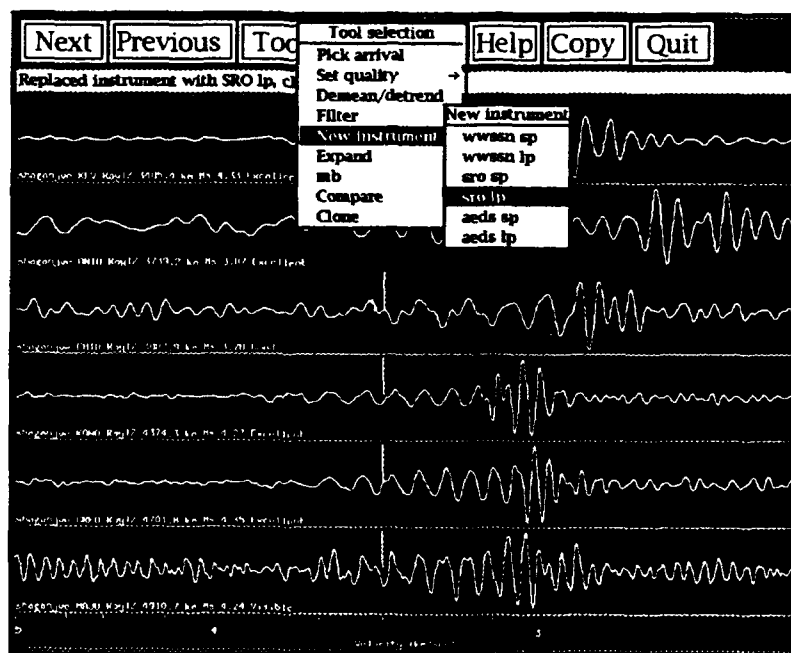
The long-period surface wave data can be accessed in the same manner as the L_g and P phase data described above, resulting in analyst station displays such as that shown in Figure 21 for the vertical component Rayleigh wave phase. It can be seen from this example that, although these traces are aligned according to a common group velocity scale, the surface wave signals are quite variable and difficult to correlate from trace-to-trace. This is at least partially due to the fact that the response characteristics of the long-period instruments used to record these data vary significantly between stations. Thus, for example, the station MAJO trace shown at the bottom of this figure was recorded through a relatively broadband system,

Figure 21.
Analyst station display of selected long-period Rayleigh wave signals for the current event.



with the result that the long-period signals of principal interest are obscured by higher frequency arrivals. In order to provide a common basis for comparison, the TOOLS menu includes a function (*New instrument*) which permits the analyst to transform the data to that which would have been observed if the same instrumentation had been employed at each station. This feature is graphically illustrated in Figure 22 where the analyst has selected the nominal SRO long-period response and converted all of the traces in this display to that response by simply designating them with the mouse. It is evident from this example that such a capability greatly facilitates quantitative comparisons and evaluation of data.

Figure 22.
Example of the specification and subsequent application of the instrument response normalization feature to the data of Figure 21.



Spectral P

Once the available long-period Rayleigh and Love wave data have been previewed, the analyst can return to the *Magnitude Measurement* menu of Figure 12 and select *Moment Tensor*, thereby initiating a process by which the observed long-period data are phase matched filtered and formally inverted to obtain a surface wave measure of seismic magnitude. While this computationally intensive process is running in the background, the analyst next selects *Spectral P* from this same menu and proceeds with an interactive determination of the network-averaged P wave spectrum corresponding to the current event. The spectrum estimated in this process can be inverted to obtain either an equivalent spectral magnitude or a direct, model-based yield estimate (Murphy, 1989), and Figure 23 shows the menu structure for the latter option, where it is indicated that the Mueller/Murphy granite (M/M Granite) source model has been selected for the current JVE event. The resulting automatic fit to the attenuation-corrected, observed spectrum is shown in Figure 24 where it is indicated that a theoretical spectrum corresponding to a yield (W) of 119 kt, a pP - P delay time (T_0) of 0.82 seconds and a pP/P amplitude ratio (A) of 0.17 provides the best overall fit to the data. Alternately, the analyst can elect to interactively change these automatically determined model parameters using the plus and minus buttons located in the box in the upper right corner of this display, to explore solutions corresponding to goodness of fit criteria not incorporated in the automatic algorithm.

Figure 23.
*Menu options
for the estima-
tion of network-
averaged P
wave spectra.*

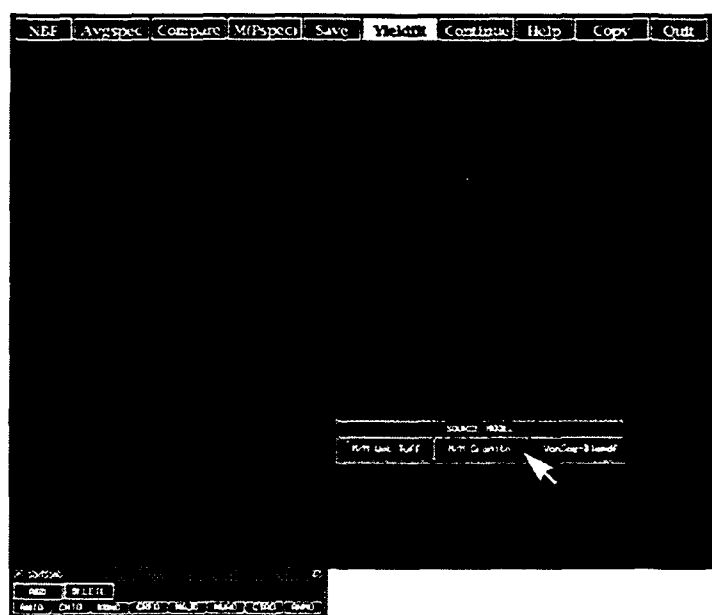
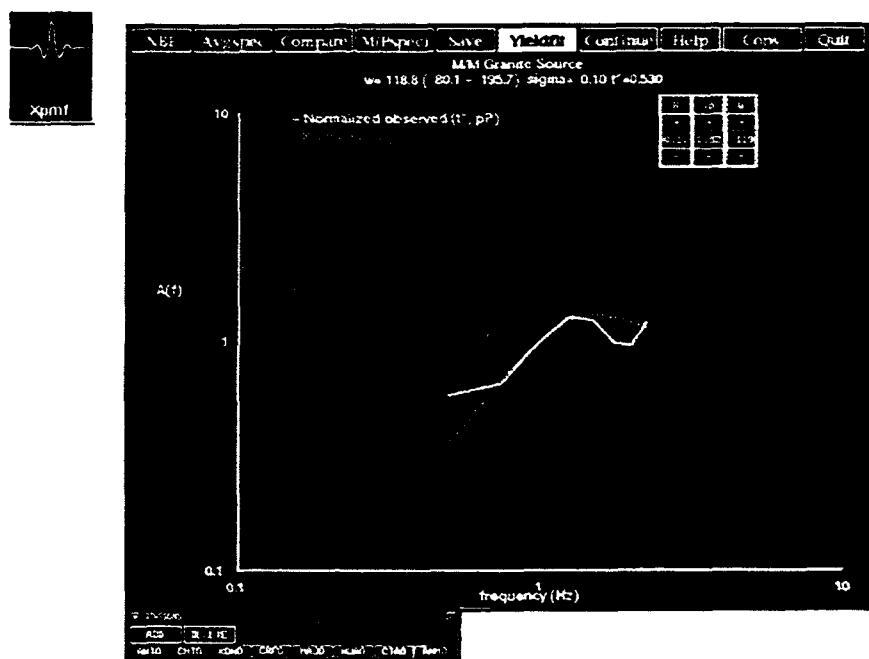


Figure 24.

Comparison of normalized observed and best-fitting theoretical network-averaged P wave spectra for the current event.



Moment Tensor

The icon appearing in the upper left corner of Figure 24 indicates that the surface wave phase matched filtering processing has now been completed, and selecting it with the mouse provides access to graphical displays of these processing results. Following review of these results, the operator can select the associated MTIS menu option to view a graphical representation of the resulting moment tensor solution shown in Figure 25 where the model fits to the Rayleigh (left) and Love (right) wave data corresponding to a tectonic release F factor of 0.13 are displayed. It is informative to examine this solution in the context of other available information regarding the test environment. This can be accomplished by

Figure 25.

Comparison of the inferred surface wave moment tensor solution for the current event with the corresponding path normalized, observed Rayleigh (left) and Love (right) wave amplitude data.

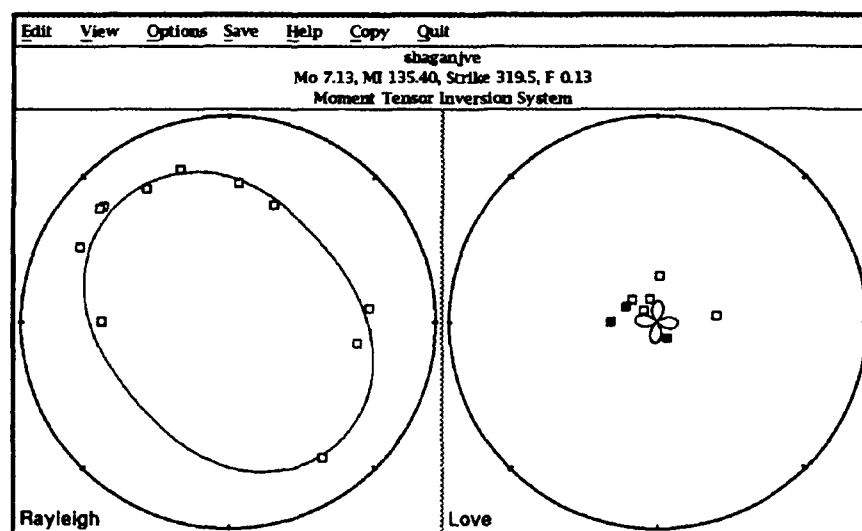
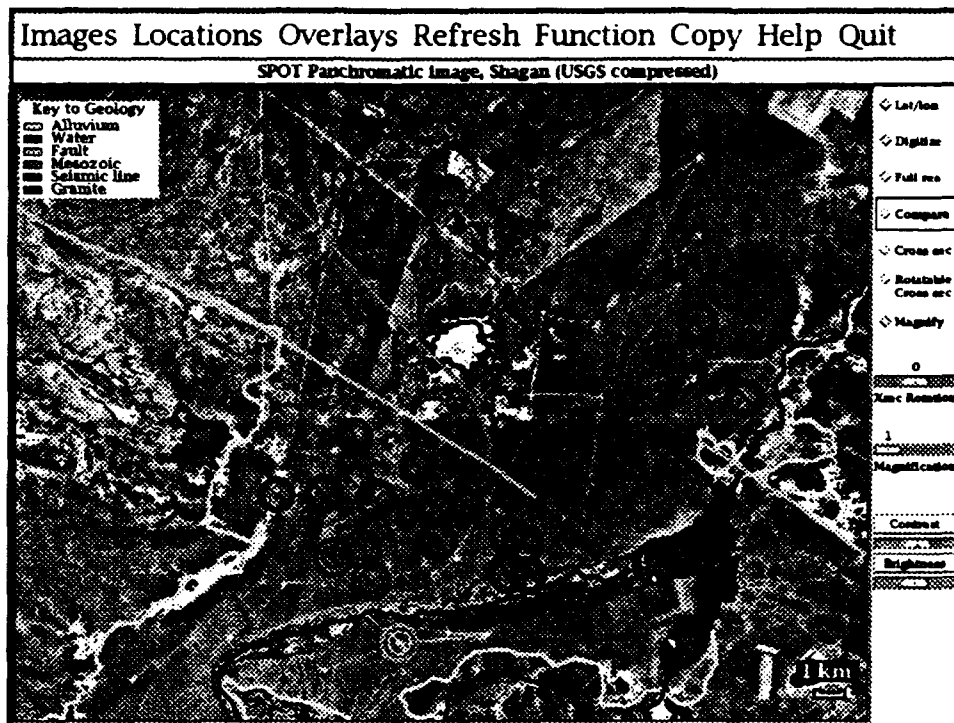


Figure 26.

Comparison of the surface wave moment tensor solution for the current event (yellow and light blue concentric circles) with those for nearby Shagan River explosions (red and dark blue concentric circles) and with the surface geologic map of the area.



returning once again to the SPOT image test site information interface and successively overlaying the current and historical moment tensor solutions, as well as the map of surface geologic features, as shown in Figure 26. In this display, the concentric circles represent the moment tensor solutions where, for the historical events, the ratio of the diameters of the red-to-blue circles is equal to the inferred tectonic release F factors and the line segments interior to the circles are parallel to the associated strike of the tectonic component. The solution for the current (JVE) event is differentiated here by an alternate color scheme in which yellow and light blue circles replace red and blue, respectively. It can be seen from this display that the solution for the current event is quite consistent with those previously determined for nearby historical events. Moreover, it is evident that the inferred strikes of the tectonic releases triggered by these explosions are parallel or subparallel to that of the mapped Chinrau fault. Thus, by using the test site information interface, the analyst is able to quickly verify that the surface wave moment tensor solution which was obtained for the current event is consistent with both the solutions from previous nearby explosions and with the regional tectonic environment in which the test was conducted.

Yield Estimation

Having determined the various seismic measures of source size (including a regional P_n magnitude not discussed above), the analyst can proceed to estimate the corresponding explosion yield and the associated uncertainty in that estimate by selecting the *Yield Estimation* feature from the FUNCTION menu of Figure 2. This yield estimation module provides an estimate of unified yield based on multiple magnitude measures and associated extremal confidence limits corresponding to different sets of constraints specified by the analyst. The confidence limits are obtained as the solution of a nonlinear programming problem in which estimates of yield for a training set of explosions are minimized and maximized over the space of admissible parameters (Rodi, 1989; Rodi and Murphy, 1990). Input to this model consists of multiple network-averaged magnitudes for the current event and a nominal m_b /yield relation based on some combination of data analysis and expert opinion, which for explosions at the Shagan River test site is taken to be (Murphy, 1990):

$$m_b = 4.45 + 0.75 \log W$$

The current module can provide estimates corresponding to five different sets of constraints, parameterized by the uncertainty in the average value of m_b at 100 kt ($m_b(100)$), the uncertainty in the slope (b) of the m_b /yield relation and the upper bound on the absolute value of the correla-

Figure 27.
Menu and sample output for the unified yield estimation module.

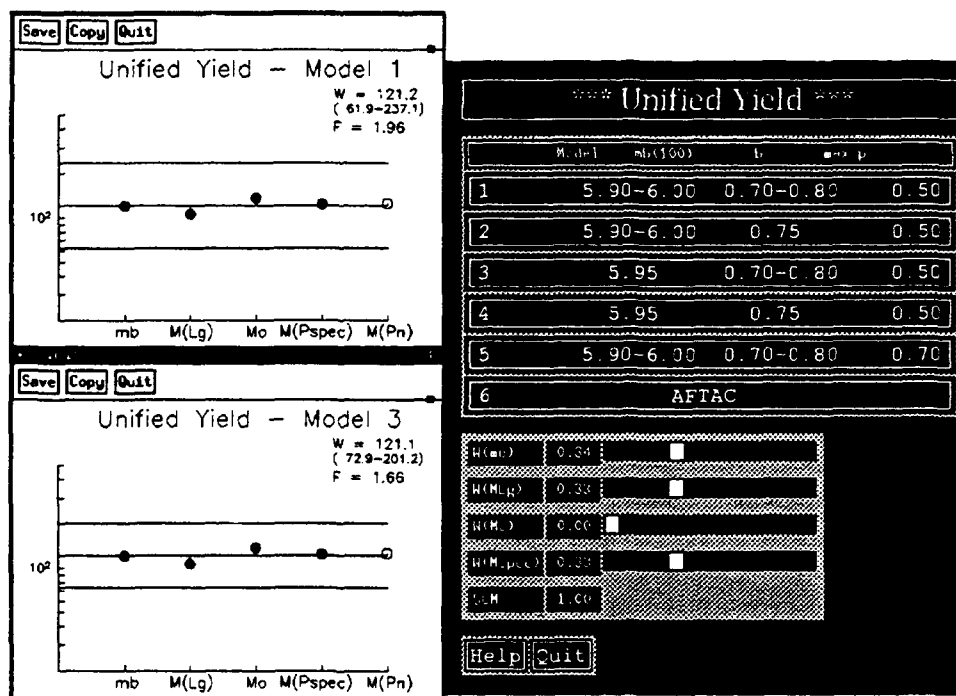
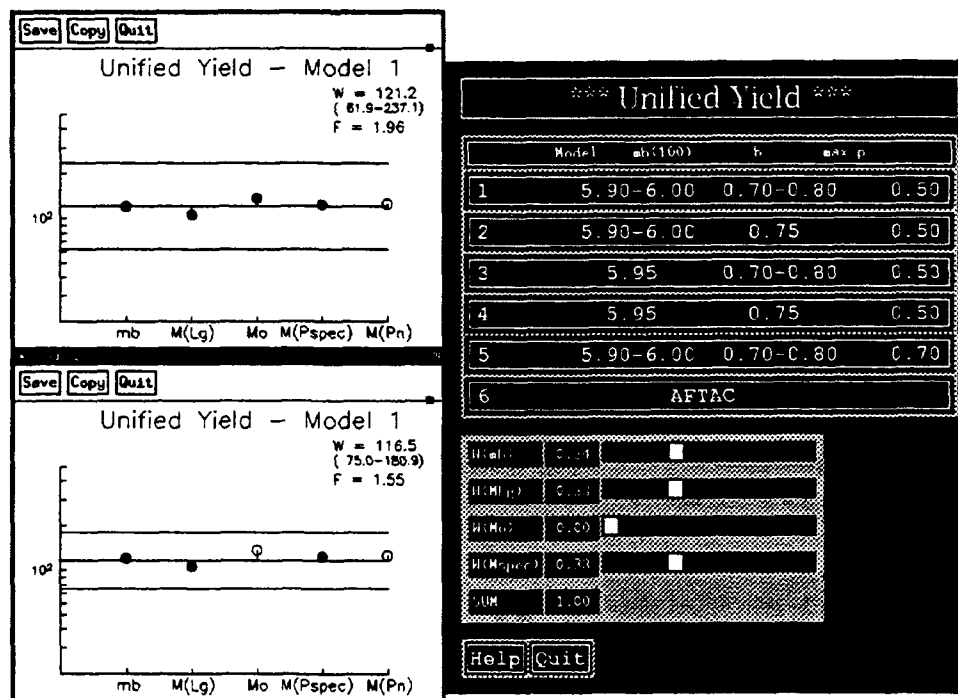


Figure 28. Comparison of unified yield estimates (W) and associated uncertainties (F) obtained with (top) and without (bottom) the surface wave moment tensor magnitude.



Statistical Summary

Given an optimum seismic estimate of unified yield and the associated uncertainty, the analyst can next proceed to assess whether this estimate is consistent with the 150 kt threshold of the Threshold Test Ban Treaty (TTBT) by selecting the *Statistical Summary* option from the FUNCTION menu. This module provides access to a variety of statistical compliance assessment tests developed by Mission Research Corporation (Gray *et al.*, 1990), as indicated by the menu displayed in Figure 29. In this example, the analyst has requested a summary of the results of three single

Figure 29.
Statistical assessment menu.

* Statistical Assessment *

Histogram of Historical Yields

Historical Yields versus Time

Single Event Test 1 (A0, B0)

Single Event Test 2 - JVE

Single Event Test 3 - Exchange Events

Single Event Test 1, 2, 3 Summary

Single Event Test - AFTAC

Mixture of Normals (A0, B0)

Mixture of Normals (A1, B1)

Mixture of Normals Comparison

True Yield: 1.0

False Yield: 0.0

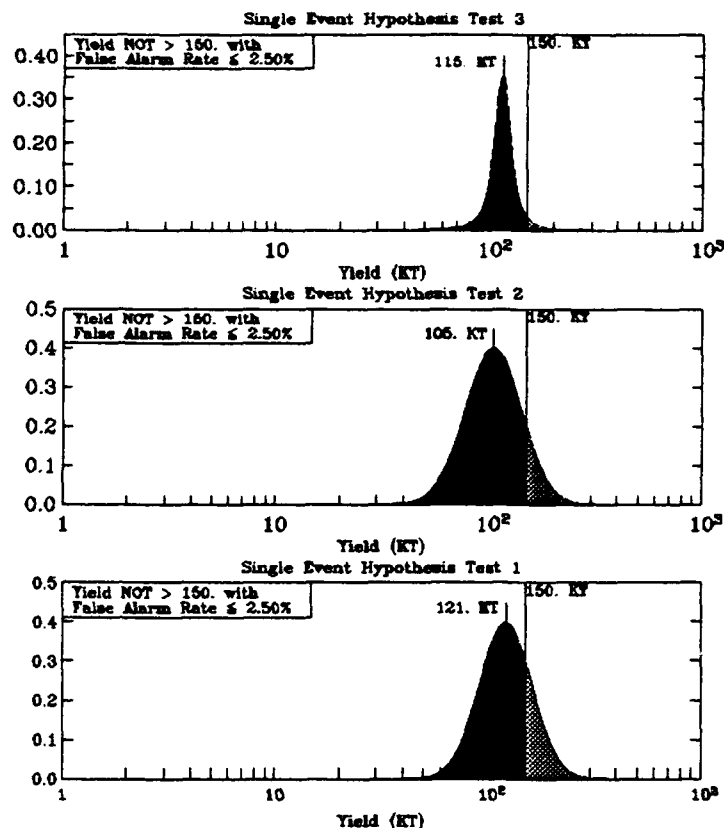
A0	1.0	A1	1.0
B0	0.0	B1	0.0
A0	0.0	A1	0.0
B0	0.0	B1	0.0

Help Quit

event compliance tests, producing the graphical summary shown in Figure 30, where the red areas under the distribution curves provide a measure of the probability of a violation of the 150 kt threshold. The formal statistical results are summarized in the boxes in the upper left hand corners of these figures, and it can be seen that the results of each of these three tests indicate that the seismic data are consistent with a yield of less than 150 kt at a specified false alarm rate of less than 2.5 percent. The resolving power of such tests can be illustrated by considering the outcome which would have resulted if these same seismic data had been observed from a test below the water table at NTS. In this case, the Shagan m_b /yield relation would be replaced by (Murphy, 1981):

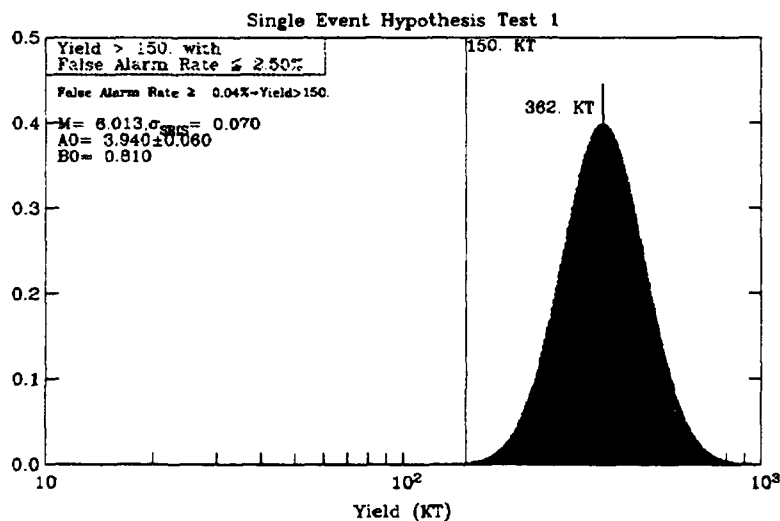
$$m_b = 3.94 + 0.81 \log W$$

Figure 30.
Comparison
of the results
of three differ-
ent tests of
seismic com-
pliance of the
current event
with the 150
kt threshold of
the TTBT.



resulting in the revised Test 1 outcome shown in Figure 31. It can be seen that under this hypothesis, the yield estimate would be 362 kt and it would be concluded that this explosion violated the 150 kt limit of the TTBT. Thus, this simple example graphically illustrates the importance of the test site magnitude bias effect which has received such intense study since the initial negotiation of the TTBT.

Figure 31.
Compliance
test results (Test
1) for the sce-
nario in which
the current
event data
were observed
from an explo-
sion below the
water table at
NTS.



Spreadsheet

Having completed the formal analysis, the *Spreadsheet* option from the FUNCTION menu can be used to provide a less formal environment for evaluating the seismic yield estimate for the current event in the context of the results obtained from analyses of previous explosions at that test site, as well as any available independent yield calibration data, as illustrated in Figure 32. In this display, the four individual seismic yield estimates and resulting unified yield for the current event are listed beneath the magnitude/yield coefficients and weights used in converting the individual magnitude measures to yields. Beneath the yield estimates for the current event is a scrollable list of corresponding yield estimates for previous explosions at that test site, together with selected calibration yields, $W(\text{calib})$, taken here for purposes of illustration to be the three Shagan River high yield values published by Bocharov *et al.* (1988). The ratios of the unified seismic-to-calibration yields are listed in the last column of this display and the corresponding average value of these ratios, and associated uncertainty (F) inferred from these limited calibration data are listed in the summary panel at the bottom of the display. For the nominal magnitude/yield relations listed at the top of this display, the average ratio is 1.085 with an associated F factor of 1.35. Figure 33 shows the results of interactively adjusting each magnitude/yield intercept (using the *Change* menu option) in such a manner that the individual average offsets are minimized. It can be seen

Figure 32.
Spreadsheet summary comparison of seismic yield estimates for the current event (09/14/88) with those obtained for selected previous Shagan River explosions.

Change Help Quit								
Magnitude/Yield Equations:								
Parameter	Mb	Mlg	Mo	Mpepec				
Slope	0.750	0.750	1.000	0.750				
Intercept	4.450	4.450	5.000	4.450				
Weight	0.250	0.250	0.250	0.250				
Current event:								
Date	M(Mb)	M(Mlg)	M(Mo)	M(Mpepec)	M(unified)	M(calib)	Source	M(u)/M(c)
09/14/88	120.586	105.358	135.519	128.280	• 121.838 •			
Other events:								
Date	M(Mb)	M(Mlg)	M(Mo)	M(Mpepec)	M(unified)	M(calib)	Source	M(u)/M(c)
11/30/68	131.826	133.046		118.032	• 127.834 •	125.000	Bocharov	1.021
11/02/72	190.546	167.494		255.858	• 204.833 •	185.000	Bocharov	1.240
12/10/72	135.936	156.075		125.122	• 139.044 •	140.000	Bocharov	0.993
01/15/65	88.444			94.915	• 91.679 •			
07/23/73	215.444	212.162		240.621	• 222.742 •			
12/14/73	85.770	77.268		69.396	• 77.478 •			
06/11/78	85.770	54.117	128.825	75.393	• 86.028 •			
08/29/78	100.000	119.858	81.283	100.825	• 100.517 •			
09/15/78	88.444	87.902	112.202	93.469	• 86.504 •			
11/29/78	120.227	106.007	120.226	106.007	• 113.117 •			
06/23/79	184.785	138.463	177.828	184.785	• 171.465 •			
07/07/79	91.201	105.682	75.858	97.275	• 92.504 •			
08/04/79	140.174	158.877	186.209	183.091	• 167.113 •			
08/18/79	153.888		104.713	148.584	• 135.668 •			
10/28/79	118.592	137.615	194.984	114.113	• 140.826 •			
12/02/79	100.000	90.088	138.038	106.007	• 108.533 •			
12/23/79	168.526		79.433	163.933	• 137.297 •			
09/14/80	251.189		213.796	213.468	• 226.151 •			
08/13/81	127.840	165.450	181.870		• 158.420 •			
10/18/81	106.333	111.003	144.544		• 120.626 •			
Summary of statistics:								
Given 3 calibration events:								
Average Unified Yield/Calibration Yield ratio:					1.085			
F factor:					1.350			

Figure 33.
Spreadsheet
summary
illustrating
the results of
interactively
modifying the
designated
magnitude/
yield rela-
tions.

Change Help Quit								
Magnitude/Yield Equations:								
Parameter	Mb	Mlg	Mo	Mpspec				
Slope	0.750	0.750	1.000	0.750				
Intercept	4.470	4.470	5.000	4.480				
Weight	0.250	0.250	0.250	0.250				
Current event:								
Date	M(Mb)	M(Mlg)	M(Mo)	M(Mpspec)	M(unified)	M(calib)	Source	M(u)/M(c)
09/14/88	113.414	99.083	135.519	115.168	• 115.798 •			
Other events:								
Date	M(Mb)	M(Mlg)	M(Mo)	M(Mpspec)	M(unified)	M(calib)	Source	M(u)/M(c)
11/30/69	123.975	125.122		107.647	• 118.914 •	125.000	Bocharov	0.951
11/02/72	179.198	157.519		233.346	• 190.021 •	165.000	Bocharov	1.152
12/10/72	127.840	146.780		114.113	• 129.578 •	140.000	Bocharov	0.926
01/15/65	83.176			86.563	• 84.870 •			
07/23/73	202.613	199.526		219.449	• 207.196 •			
12/14/73	80.882	72.066		63.290	• 72.298 •			
06/11/78	80.662	50.894	128.825	68.760	• 82.285 •			
08/29/78	94.045	112.720	81.283	92.045	• 95.023 •			
09/15/78	83.176	82.667	112.202	85.245	• 80.823 •			
11/29/78	113.068	99.894	120.228	98.679	• 107.416 •			
06/23/78	173.780	130.217	177.828	168.526	• 162.588 •			
07/07/79	85.770	99.388	75.858	88.716	• 87.433 •			
08/04/79	131.826	148.508	186.208	166.981	• 158.631 •			
08/18/79	144.544		104.713	135.519	• 128.259 •			
10/28/78	108.648	129.420	184.984	104.072	• 134.531 •			
12/02/79	94.045	84.723	138.038	98.679	• 103.371 •			
12/23/79	158.489		79.433	149.509	• 129.144 •			
09/14/80	238.229		213.798	194.685	• 214.904 •			
08/13/81	120.227	155.587	181.970		• 152.598 •			
10/18/81	100.000	104.382	144.544		• 116.312 •			
Summary of statistics:								
Given 3 calibration events:								
Average Unified Yield/Calibration Yield ratio:					1.010			
F factor:					1.263			

that these modifications eliminate the average bias in the unified seismic yield estimate (i.e., Avg Bias = 1.01) and reduces the F factor to 1.263. This example illustrates how the spreadsheet module provides a capability for the analyst to rapidly explore the effects of alternate hypotheses on the seismic yield estimation process.

Event Summary

Once the processing has been completed for the current event, the analyst can produce a one-page summary of the analysis results by selecting the Event Summary option from the FUNCTION menu. As is indicated in Figure 34, listed results include the date, origin time and location of the explosion, the derived unified seismic yield and its associated uncertainty, the results of the statistical test of compliance of the current event with the 150 kt limit of the TTBT, a tectonic release characterization of the event based on the surface wave moment tensor analysis and, if available, the CORTEX yield estimate for the explosion. In addition, each of the estimated seismic magnitudes is listed together with its associated yield estimate and assigned weight in the determination of the unified yield estimate.

Figure 34.
Summary of
analysis results
for the selected
event.

Copy

Help

Quit

Event Summary

Test Site : Shagan
 Date : 14 September 1988
 Origin Time : 4:0: 0.00 UT
 Location : 49.8788N, 78.8225E

Date of Analysis : Sep 29, 1992

Unified Seismic Yield : 116.5 KT
 CORRETEX Yield : Not available
 Unified Seismic Uncertainty : F = 1.55 (75.0 kt < W < 180.9 kt)

Threshold Assessment : Accept the null hypothesis that
 the yield is less than 150kt
 (2.5% significance level test)

Tectonic Characterization : F = 0.13, Strike = 319 degrees

The conclusions presented above were based on the following measurements:

Measurement	Individual Magnitudes and Yields		
	Yield	Magnitude	Rel.Weight
mb	120.500	6.011	0.340
M(Lg)	105.900	5.967	0.330
M(o)	136.500	7.132	0.000
M(PSpec)	123.900	6.026	0.330
M(Pn)	125.600	6.025	0.000

The sample analysis session described above has provided an overview of some of the capabilities which are currently available within the Yield Estimation System. As was evident from the menu structures shown in the graphical displays, there are, in addition, many other features which were not exercised here in order to hold the description to a manageable length. A complete description of all currently available system options is provided in Appendix C.

3

Summary

In this report we have presented an in-depth description of the research investigations directed toward the development of a comprehensive new seismic yield estimation system for underground nuclear explosions. In its current configuration, the YES system is applicable to underground nuclear explosions at the Soviet Shagan River and Novaya Zemlya test sites and encompasses a database of more than 15,000 digital seismograms recorded at stations of the USAEDS, GDSN, CDSN and IRIS networks from explosions at these two sites. For both test areas, information regarding the explosion source environment is presented to the analyst in the context of SPOT satellite images of the sites, together with associated surface and subsurface geologic information and DMA topographic data. The on-line database for YES also contains a wide variety of tabular information, including complete event and station location files containing both classified and unclassified locations, standard travel-time tables for the seismic arrivals used for yield estimation, propagation path and station corrections for use in magnitude determinations and a comprehensive instrument response database. The instrument database encompasses a compilation of over 750 different response histories collected from the USGS, AFTAC, IRIS and others which detail the characteristics of the various recording instruments as a function of station, channel and date.

The capabilities and functionality of the YES system were graphically illustrated in Section II using displays of the screens encountered by an analyst in a typical processing session. The selected capabilities displayed in this sample session were related to a more complete definition of the system functionality through references to a series of appendices containing a detailed script of the operator actions required to reproduce the sample session (Appendix B), a complete description of all currently available system options (Appendix C), as well as information regarding soft-

ware and hardware implementation requirements (Appendix A), a top level schematic diagram of the main modules of the system and their interdependencies (Appendix D), and a description of an off-line module which has been implemented to permit the analyst to add new events and seismic data to the system (Appendix E). Taken together, Section II and its associated appendices provide a concise description of the results of the YES system development effort.

4

References

Gray, H. L., W. A. Woodward and G. D. McCartor (1990), "Statistical Issues Concerning Testing for Compliance to the TTBT," paper presented at 12th Annual DARPA/GL Seismic Research Symposium, Key West, Florida, GL-TR-90-0212, ADA226635.

Herrin, E., E. P. Arnold, B. A. Bolt, G. E. Clawson, E. R. Engdahl, H. W. Freedman, D. W. Gordon, A. L. Hales, J. L. Lobdell, O. Nuttli, C. Romney, J. Taggart, and W. Tucker (1968), "1968 Seismological Tables for P Phases," *Bull. Seism. Soc. Am.*, 58, pp. 1193-1241.

Murphy, J. R. (1981), "P-Wave Coupling of Underground Explosions in Various Geologic Media," in: *Identification of Seismic Sources - Earthquake or Underground Explosion*, Proceedings of the NATO Advanced Study Institute, D. Reidel Publishing Company.

Murphy, J. R. (1989), "Network-Averaged Teleseismic P-Wave Spectra for Underground Explosions, II: Source Characteristics of Pahute Mesa Explosions," *Bull. Seism. Soc. Am.*, 79, pp. 16-31.

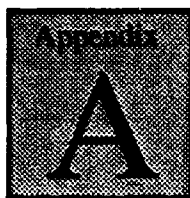
Murphy, J. R. (1990), "A New System for Seismic Yield Estimation of Underground Explosions," paper presented at the 12th Annual DARPA/GL Seismic Research Symposium, Key West, Florida, GL-TR-90-0212, ADA226635.

Murphy, J. R., J. L. Stevens, D. C. O'Neill, B. W. Barker, K. L. McLaughlin, M. E. Marshall (1991), "Development of a Comprehensive Seismic Yield Estimation System for Underground Nuclear Explosions," Annual Technical Report to Phillips Laboratory, PL-TR-91-2161, ADA240814.

Ringdal, F. (1983), "Magnitudes from P Coda and L_g Using NORSAR Data,"
in NORSAR Semi-Annual Technical Summary, 1 Oct 82 - 31 Mar 83,
NORSAR Sci. Rep. No. 2-82/83, NTNF/NORSAR, Kjeller, Norway.

Rodi, W. L. (1989), "A Mathematical Program for Unified Yield Estimation,"
S-CUBED Memorandum to DARPA Yield Technical Review Panel,
December 22.

Rodi, W. L. and J. R. Murphy (1990), "Numerical Experiments With Unified
Yield Estimation," S-CUBED Technical Memorandum to DARPA Yield
Technical Review Panel, April 19.



Requirements and Startup Instructions

Hardware Requirements

The YES system is designed to run on SUN-4 and SUN SPARCStation computers with a minimum of 32MB of resident memory. It uses the standard SUN 8-bit color monitor with a resolution of 1152x900 pixels, as well as the standard SUN 3-button mouse. YES also requires a minimum of 1 gbyte of disk storage to hold the complete system and its required data. To use the reporting and printing capabilities of the YES system, it is suggested that the computer be set up to print to a postscript printer via the "lpr" command.

Software Requirements

YES is written in C and FORTRAN and uses the X Window System software, version X11 revision 4. It also uses the Hewlett Packard widget set extension to X and the Motif widget set, release 1.1. It has been successfully compiled using the standard SUN bundled C compiler and the SUN 1.3.1 FORTRAN compiler, and is designed to run under the SUN operating system version SUN-OS 4.1.0 or later. YES also has an interface to the desktop publishing package FrameMaker, version 3.0 X, which allows the user to generate, edit and print a report of the analysis.

Startup Instructions

The following instructions assume that the X Window System and YES have been installed according to S-CUBED specifications. Also refer to the information on mouse and window techniques in Appendix C before proceeding.

To bring up the X environment and run YES you must do the following:

1. Login to UNIX at the console.
2. Add /usr/bin/X11 to your search path, if it is not already there, and issue the command:
prompt> rehash
(where prompt> denotes the UNIX operating system prompt).
3. Ensure that the files xinitrc and twmrc as provided on the distribution tape have been copied to .xinitrc and .twmrc in your home directory.
4. Issue the command:
prompt> startx
and wait until an X terminal window appears on your screen.
5. Move the cursor into the X terminal window and change to the main directory where YES has been installed.
6. Issue the command:
prompt> source Init
7. Issue the command:
prompt> yieldsys&

Shutdown Instructions

To shutdown the system:

1. Choose *Quit* from the YES main menu.
2. Exit X by pointing outside any window. Click and hold the right button. Move the pointer down to menu item *Exit X Windows*, stop,

then move to the right and release on *Select if you're sure*.

3. Logout of UNIX at the console.

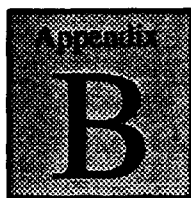
FrameMaker Instructions

FrameMaker version 3.0 X or later must be set up on the Sun workstation as per the installation manual that comes with the software package.

1. To set up the resources to manipulate the color images, edit the .Xdefaults file in your home directory to include the following resources:

Maker.clientBitmapSize: 3000000

Maker.colorImages: True



Script For Sample Session

In this section, all of the operator actions required to duplicate the sample session shown in Section II are specified. Note that when run in a classified environment, the values of some of the parameters and processing results will be somewhat different from those shown here. A full description of all system options is provided in Appendix C, including details regarding menu structures and the mouse actions required to initiate specific actions. All figures mentioned in this section are found in Chapter 2 of this manual.

Starting the pro- gram

The procedures required to initiate and start the program are specified in Appendix A. To recap:

1. **Change to the YES directory.**
2. **Type *source Init.***
3. **Type *yieldsys&*.**

Once the program has been started, the first screen display is the title page. Clicking anywhere within the display brings up the main menu. A site and an event are normally selected as the first step in the analysis.

Main Menu

1. **Choose *Balapan (Shagan)* from the SITE menu.**
2. **Choose *Shagan Events->1980-1989->1988->September 14 (JVE)* from the EVENT menu.**

This event will be referred to as the current event.

After a site and event have been chosen, one can proceed to analyze the near-source environment of the current event.

Satellite Image

1. Choose *Satellite Image* from the **FUNCTION** menu.

This brings up the satellite image of the test site. It will come up with symbols showing the locations of all the events that occurred at the test site and the current event location highlighted (see Figure 3).

2. Click on the **current event diamond**.

A description of the event is displayed in the information bar below the menu. Experiment likewise with other events (i.e. click on them).

Full res

1. Click on *Full res* in the side menu and then in the center of the crater located at the northern end of the lake.

Once the 10 m resolution image of the crater has come up (see Figure 4), full resolution images of adjacent areas can be viewed by clicking near the edges of the image.

2. Choose *Satellite image* from the **IMAGES** menu.

The original satellite image is now displayed.

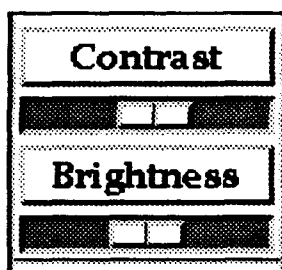
3. Click again on the *Full res* button to turn it off.

Contrast and Brightness

1. Adjust the *Contrast* and *Brightness* sliders in the side menu.

This reverses contrast and alters the brightness of the image (see Figure 5).

2. Click on the *Contrast* and *Brightness* buttons to restore the original settings.



Use the slider bars to adjust the values

Surface Geology

1. Choose *Surface geology* from the **OVERLAYS** menu.
2. Choose *Current event* from the **OVERLAYS** menu.

The display will look like Figure 6.

3. Choose *Remove Overlays* from the **REFRESH** menu.

Topographic Map

1. Choose *Surface topography* from the IMAGES menu.
2. Choose *Topography contours* from the OVERLAYS menu.
3. Choose *Current event* from the OVERLAYS menu.

The display should now look like Figure 7.

4. Choose *Satellite image* from the IMAGES menu.

Cross Section

1. Choose *Event locations(SPOT)* from the LOCATIONS menu.
2. Click on *Cross sec* in the side menu.
3. Click below the current event location and again near the northern extremity of the display (see insert in Figure 8).

The cross section of the site along the line is then displayed (see Figure 8).

4. Click on the *Quit* button to return to the satellite image.
5. Click again on *Cross sec* in the side menu to turn it off.

Granite Surface

1. Choose *Depth to granite* from the IMAGES menu.
2. Choose *Subsurface contours->Depth to top of granite* from the OVERLAYS menu.
3. Choose *Current event* from the OVERLAYS menu.

Figure 9 shows what the screen should look like at this point.

4. Choose *Satellite image* from the IMAGES menu.
5. Iconify the Satellite Image module.

World Map

1. Choose *World Map* from the main FUNCTION menu.
2. Choose *Teleseismic P* from the PHASE menu.
3. Choose *Teleseismic P->ANMO* from the STATION menu.

This draws the great circle path shown in Figure 10.

4. Click on the REFRESH button.

This removes the stations. Repeat steps 2-4 to draw the great circle path for phase L_g and the NORSAR(N01A0) station shown in Figure 10.

5. Click on QUIT to return to the main menu.

Analyst Station

1. Choose L_g from the PHASE menu.
2. Choose *Analyst Station* from the main FUNCTION menu.
This displays the L_g waveforms as shown in Figure 11.
3. Click on the QUIT button and return to the main menu.

RMS L_g Startup

1. Choose *Magnitude Measurement->RMS L_g* from the FUNCTION menu.

This spawns off a process, and when done, the following icon pops up. While this process runs in the background, continue with the rest of the analysis.



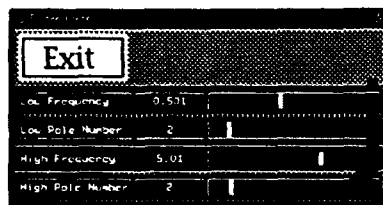
The RMS L_g icon

Filter

1. Choose *Teleseismic P* from the PHASE menu.
2. Choose *Analyst station* from the FUNCTION menu.

This displays the first six teleseismic P waveforms as shown in Figure 13.

3. Click on the NEXT and PREVIOUS buttons to page through the waveforms.
4. Choose *Filter* from the TOOLS menu.
5. Set:
Low Frequency = 0.5
Low Pole Number = 2
High Pole Number = 2
High Frequency = 5.0



Move the slider bars or click anywhere in the slider box to change the settings

6. Click on the station MAJO waveform.

This applies the selected bandpass filter (second-order, 0.5 to 5 Hz) to the MAJO waveform as shown in Figure 14. To apply this same filter to other waveforms, just click on them.

7. Click on the EXIT button once done with the filter.

Compare

1. Choose *Compare* from the TOOLS menu.
2. Click on the station KONO waveform.
3. De-iconify the Satellite Image icon.
4. Choose *Remove locations* from the REFRESH menu to remove any event locations on the image.
5. Choose *Compare events* from the LOCATIONS menu.
6. Click on *Compare* in the side menu.
7. Double-click on five events surrounding the current event.

The display should look like Figure 15.

8. Choose *Analyst station* from the Satellite Image FUNCTION menu.

This displays the KONO teleseismic P waves for the selected events beneath that for the JVE event.

Clone

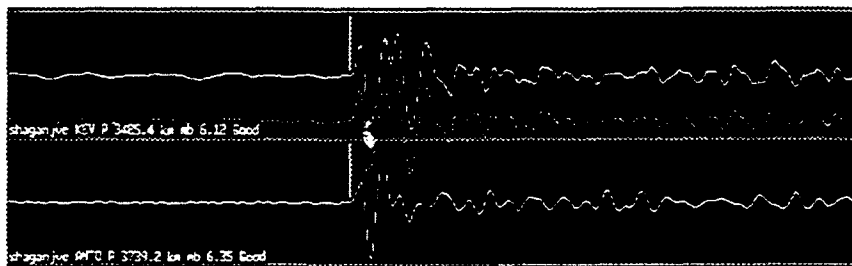
1. Choose *Clone* from the TOOLS menu.
2. Click on the JVE trace.

A red copy of the JVE trace appears and the cursor changes to a pointing hand.

3. Compare the trace with the others.

Reposition the red trace adjacent to any other desired trace as illustrated in the figure above. Also see Figure 16. When finished with the comparison, click again anywhere in the display to get rid of the clone.

4. Click on the QUIT button to return to the satellite image.



Move the hand with the mouse and the red trace follows it.

5. Choose *Remove locations* from the REFRESH menu.
6. Iconify the Satellite Image.

The Analyst Station display should now be on the screen.

Expand and m_b

1. Choose *Expand* from the **TOOLS** menu.
2. Click on station **ANTO's** waveform.

This brings up the waveform in expanded form as shown in Figure 17. All the tools are still available for use in this mode.

3. Choose m_b from the **TOOLS** menu.
4. Measure amplitude and period.

Draw a rectangle over the selected half cycle of motion by clicking the cursor at the peak, dragging the cursor to the trough while holding down the mouse button and then releasing the mouse button (see Figure 17).

5. Click on the **EXIT** button.

The original full page screen is displayed. Do the measurements for all other waveforms using steps 2-6. Note that the m_b tool can also be used in the full page display. Therefore, the measurements need not all be done in expanded mode although it is easier on the eye.

6. Choose *Interface file* from the **FUNCTION** menu.

This saves the amplitude and period measurements along with other information for use by other modules.

7. Click on the **QUIT** button to get back to the main menu.

Magnitude Measure- ment

1. Choose *Magnitude Measurement->mb* from the **FUNCTION** menu.

A display similar to that of Figure 18 will result. Not all the station magnitudes shown in Figure 18 will be displayed if not all of them were measured in step 5 under *Expand and m_b* .

2. Click on the **QUIT** button.

RMS L_g

1. De-iconify the **RMS L_g** icon.

The display should now look like Figure 19.

2. Choose **NORS** from the **RESIDUAL** menu.
3. Click on the **QUIT** button.

M_{Lg} and m_b comparison

1. De-iconify the **Satellite Image**.
2. Choose *Historical magnitude data->Mb- M_{Lg} (NORSAR)* from the **OVERLAYS** menu.

3. Choose *Event magnitude data->Mb-MLg* from the **OVERLAYS** menu.

The display should look like Figure 20.

4. Choose *Quit* from the **QUIT** menu.

Instrument Response

1. Choose *Rayleigh(vertical)* from the **PHASE** menu.
2. Choose *Analyst Station* from the **FUNCTION** menu.

The display should look like Figure 21.

3. Choose *New instrument->sro lp* from the **TOOLS** menu as shown in Figure 22.
4. Click on each of the waveforms.

This transforms all the waveforms to the same instrument response.

5. Click on the **QUIT** button.

Moment Tensor Startup

1. Choose *Magnitude Measurement->Moment tensor* from the **FUNCTION** menu.

This spawns a background process and the following icon pops up when done. Continue the analysis while this is being processed.



The Xpint icon

Spectral P

1. Choose *Magnitude Measurement->Spectral P* from the main **FUNCTION** menu.
2. Click on *NBF*.

This brings up a display of the P wave signal and noise spectra for the first station.

3. Click on *Continue* until all stations have been processed.
4. Click on *Avgspec*.

The resulting display shows a comparison of the estimated network-averaged P wave spectrum (yellow line) with that expected on average for an explosion having the current event m_b value (dashed red lines).

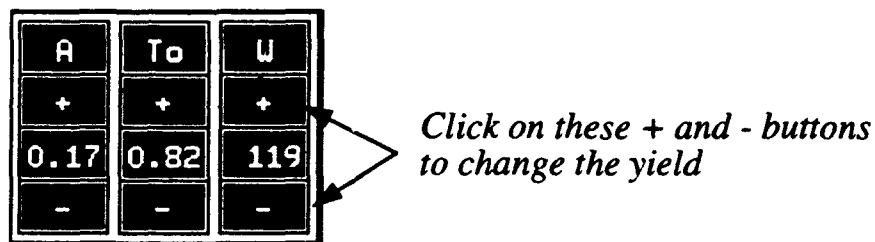
5. Click on *Yieldfit*.
6. Click on *M/M Granite* (see Figure 23).

This initiates a process by which the theoretical solution corresponding to the Mueller/Murphy granite source model which provides the best fit to the attenuation-corrected observed spectrum is automatically determined and displayed. The yield value corresponding to this best-fit solution is listed at the top of the display together with its associated upper bound uncertainty.

7. Click on *Continue* twice.

This skips through the graphs to obtain the final automatic solution with the final yield(W) and $pP(A, T_0)$ values shown in the box in the upper right-hand corner of the display (see Figure 24).

8. Change the yield W from 119 kt to 150 kt and then back down to 119 kt by using the + and - buttons shown below.



9. Click on the *QUIT* button.

This takes you back to the main menu.

Moment Tensor

1. De-iconify the Xpmf icon.

This brings up a display of the phase-matched filter output for the first long-period station. Since the data from the JVE event have already been filtered, continue with the moment tensor inversion analysis.

2. Choose *Run MTIS* from the *MTIS* menu.
3. Click on some of the green and red squares.

Individual station information is displayed in the information bar. Also see Figure 25.

4. Choose *SPOT image* from the *VIEW* menu.

This creates a graphical representation of the moment tensor solution that is used in the Satellite Image module.

5. Choose *Confirm Quit?* from the QUIT menu.

This takes you back to the Xpmf display. Quit from it similarly.

6. De-iconify the Satellite Image.

Remove any overlays on the image using the REFRESH menu.

7. Choose *Event magnitude data->Moment Tensor* from the OVERLAYS menu.

8. Choose *Historical magnitude data->Moment Tensor* from the OVERLAYS menu.

9. Choose *Surface geology* from the OVERLAYS menu.

The display should now look like Figure 26.

10. Choose *Quit* from the QUIT menu.

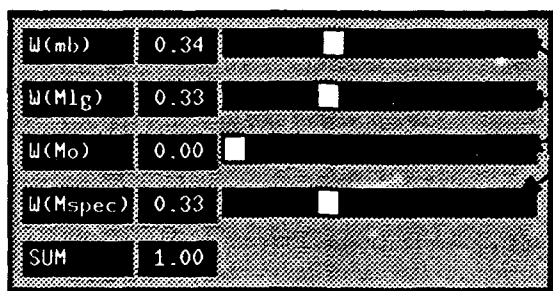
Yield Esti- mation

1. Choose *Yield Estimation* from the main FUNCTION menu.

2. Double-click on the first line that reads $a=4.45$ $b=0.75$.

3. Click on MODEL 1 and then on MODEL 3.

The display should look like Figure 27.



*Use these sliders to
set the weights*

4. Set the weights to 0.34, 0.33, 0.00 and 0.33, respectively.

5. Click on MODEL 1 again.

The display should look like Figure 28.

6. Click on the *Save* button in the lower left display.

7. Click on the QUIT button.

Statistical Summary

1. Choose *Statistical Summary* from the main FUNCTION menu.

2. Click on *Single Event Test 1 (A0,B0)*.

After a few seconds an icon comes up.

3. Click on the *Save* button at the top of the display.
4. Click on the icon to see the test results.
5. Click on the **QUIT** button.

Return to the statistical assessment options menu. Use steps 2-4 to run *Single Event Test 2 -- JVE* and *Single Event Test 3 -- Exchange Events*.

6. Click on *Single Event Test 1,2,3 Summary*.
7. Click on the icon to see the test results.

The display should look like Figure 30.

8. Click on the **QUIT** button.

Return to the statistical assessment options menu.

A0	3.94		A1	3.94	
B0	0.81		B1	0.81	
A0 sigma	0.06		A1 sigma	0.06	

Use these sliders to set A0 and B0

9. Set $A0 = 3.94$ and $B0 = 0.81$.
10. Click on *Single Event Test 1 (A0,B0)*.

When the icon comes up, click on it to look at the test results. The display should look like Figure 31.

11. Click on the **QUIT** button and return to the statistical assessment menu.
12. Click on the **QUIT** button and return to the main menu.

Spreadsheet

1. Choose *Spreadsheet* from the main **FUNCTION** menu.

The spreadsheet shown in Figure 32 comes up.

2. Select M_b *magnitude/yield parameters* from the **CHANGE** menu.

A window with sliders pops up. Use the sliders to set the intercept to 4.47.

3. Click on the *Apply* button.
4. Select M_{Lg} *magnitude/yield parameters* from the **CHANGE** menu.

Use the sliders to set the intercept to 4.47 and click on the *Apply* button.

4. Select M_{Pspec} magnitude/yield parameters from the CHANGE menu.

Use the sliders to set the intercept to 4.48 and click on the *Apply* button. The spreadsheet should now be in the form shown in Figure 33.

5. Select *Quit* to return to the main menu.

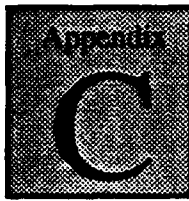
Event Summary

1. Choose *Event Summary* from the FUNCTION menu.

This brings up the current event summary page shown in Figure 34.

Quitting the pro- gram

1. Choose *Quit* from the QUIT menu.



Reference

Introduction

This section provides a description of the available options in the YES system. It describes the function and usage of every module and its menus and buttons. Following is a review of basic mouse and window techniques required by the user to work with YES.

Mouse Techniques

Point To point, position the cursor on something you want to choose.

Click To click, point to something and then briefly press and release the left mouse button.

Double Click To double-click, point to something and then rapidly press and release the left mouse button twice.

Drag To drag, point to something, press and hold down the left mouse button as you move the cursor to another position, and then release the mouse button.

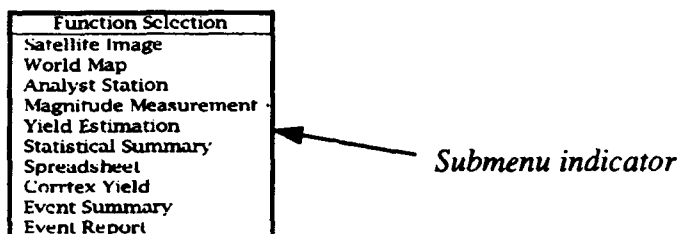
Highlight a button To highlight or turn on a button, position the pointer on the button name and click on it.



Choose from a pulldown menu To choose an option from a pulldown menu, press and hold down on the menu button name to pull down a menu, drag the highlight to the option you want and then release the mouse button.

Choose from a submenu

To choose an option from a submenu, first pull down the menu that contains the submenu. While holding down the mouse button, drag diagonally to the submenu indicator (arrow) to pull down the submenu. Drag the highlight to the required option in the submenu before releasing the mouse button.



Window Techniques

Move a window

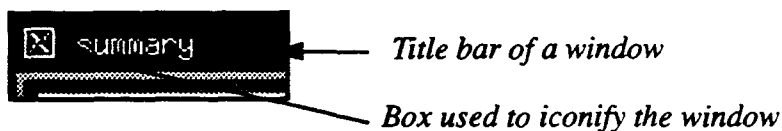
To move a window, point to the title bar of the window to be moved. Click and hold down the middle mouse button. Drag the window to the desired location and release the mouse button.

Iconify a window

To iconify a window, point to the small box in the far left of the top border and click the left button. The iconified window can be moved by clicking and holding the middle button inside the icon and dragging.

De-iconify a window

To de-iconify a window, point to the icon and click on the left mouse button.

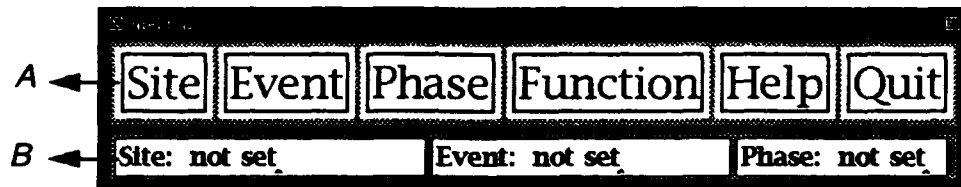


Printing the contents of a window

Specific to the YES system is a feature that permits the user to capture and print the picture which is currently being displayed in a window. This feature is provided via the COPY button which is included in each of the FUNCTION module menus. If this menu item is selected, a screen-dump of the current window is sent to the printer. If, however, the menu item is selected following the selection of *Event Report* from the main FUNCTION menu, then the image is stored in a temporary file which will subsequently be accessed by the Event Report module.

Main Menu

The main menu provides top level access to the system. It consists of six menu buttons which can be used to initiate (SITE, EVENT, PHASE, FUNCTION) or terminate (QUIT) action within the system, or to view on-line information regarding the operating characteristics and parameters of the system (HELP). Choosing any of these buttons causes a series of pull-down menus to be activated from which the various system options can be selected.



A - the main menu buttons

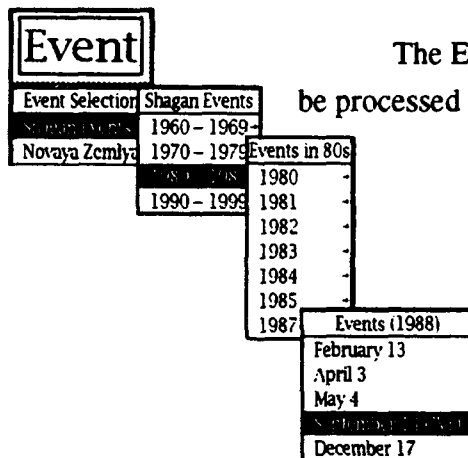
B - the information bar that indicates the selected site, event and phase

Site



The SITE menu button is used to select the nuclear test site at which the explosion to be analyzed was detonated. Currently, the choices are limited to the *Soviet Shagan River (Balapan)* and *Novaya Zemlya* test sites. Generally, a selection must first be made from this menu before making any other selections.

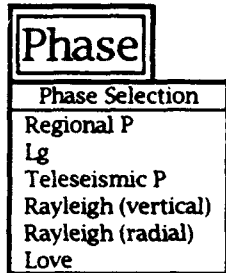
Event



The EVENT menu button is used to select the specific explosion to be processed from among those for which digital seismic data are currently

available on the system.

Phase

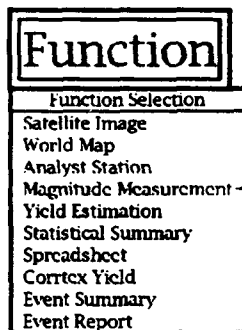


The PHASE menu button is used to select from among the six seismic arrivals for which data are currently available on the system. These consist of:

- the initial P and L_g arrivals recorded at regional distance stations (*Regional P*, L_g),
- the initial short-period teleseismic P arrivals (*Teleseismic P*),
- the three orthogonal components of the long-period surface waves (*Rayleigh (vertical)*, *Rayleigh (radial)*, and *Love*).

A test site and an explosion must be specified from the SITE and EVENT menus before a phase is selected.

Function



The FUNCTION menu is used to provide access to the ten principal computational and analysis modules of YES. The brief overviews of these modules which are presented below are followed in subsequent sections by complete descriptions of their functionality. Both the test site and explosion of interest should be specified before selecting from this menu.

Satellite Image

This module provides access to an interactive test site information interface built upon displays of SPOT satellite images of the Shagan River and Novaya Zemlya test sites.

World Map

This module provides a capability to display the map locations of stations which have recorded digital seismic data from the selected event.

Analyst Station

This module provides the capability to access and display the digital seismic waveform data available from the explosion under investigation and to interact with them to extract the parametric data required for determination of the various magnitude measures. In addition to the test site and event, the seismic arrival of interest must be selected from the PHASE menu before activating this module.

Magnitude Measurement

This module provides access to the algorithms which can be used to semi-automatically compute network-averaged magnitudes from the waveforms and parameters corresponding to the individual seismic arrivals previously reviewed by the operator in the Analyst Station module. At the present time, five separate magnitude measures based on teleseismic P waves (m_b , *Spectral P*), long-period Rayleigh and Love waves (*Moment Tensor*), and regional P and L_g waves (*Regional P*, *RMS L_g*) can be estimated using this module.

Yield Estimation

This module provides access to a statistical module which permits the operator to obtain unified yield estimates corresponding to the multiple, network-averaged magnitudes determined using the Magnitude Measurement module, as well as quantitative measures of the uncertainty in those estimates.

Statistical Summary

This module provides access to a variety of statistical tests which can be used to quantitatively assess seismic compliance with the 150 kt threshold level of the TTBT.

Spreadsheet

This module provides the analyst with the capability to evaluate the seismic yield estimate for the current event in a standard spreadsheet analysis

environment, in the context of the results obtained from analyses of previous explosions at that test site, as well as any available independent yield calibration data (e.g., CORRTEx).

CORRTEx Yield

This module provides access to an interface which permits the analyst to enter a CORRTEx yield estimate for the current event, if such an estimate is available.

Event Summary

This menu item provides access to a one page summary of the results obtained by applying the YES to the digital seismic data recorded from the selected explosion.

Event Report

This module provides access to a semi-automatic report generation module which permits the user to document the results of a completed event analysis in a color report of standard format.

Help



In this and all subsequent modules to be described, the HELP menu is used to access on-line information regarding the mode of activation and functionality of the various menu options in the current display.

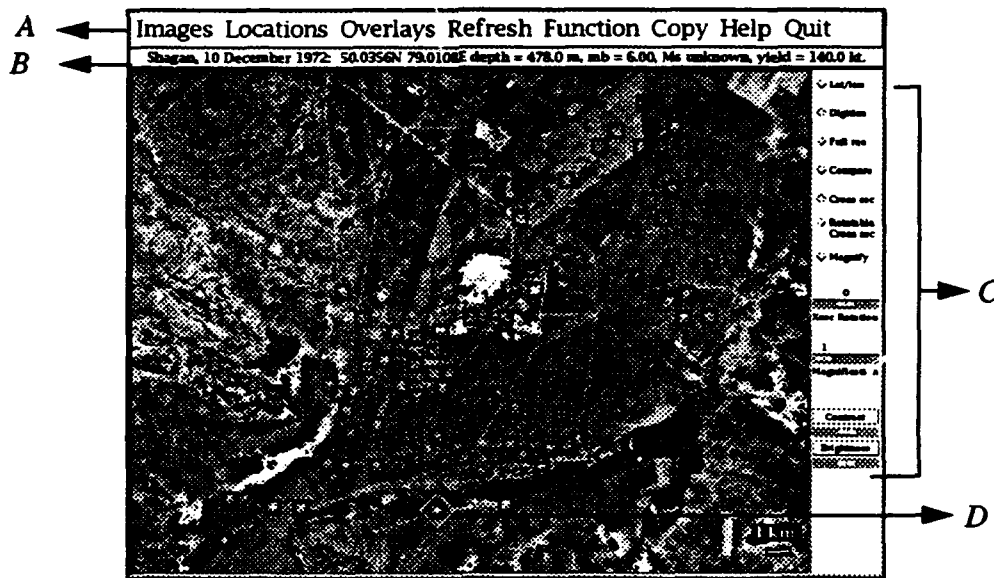
Quit



In this and all subsequent modules to be described, the QUIT menu is used to terminate the operation of the process which is currently running. Choosing this button activates a pop-up which must also be chosen to verify the request to terminate the program.

Satellite Image

As was indicated in the summary overview presented in the preceding section, selection of the *Satellite Image* option from the main FUNCTION menu provides access to an interactive test site information interface built upon displays of SPOT satellite images of the Soviet Shagan River and Novaya Zemlya test sites. For the purposes of this application, the image for the Shagan River test site has been compressed to an effective resolution of about 30 m so that the entire test site can be viewed on a single screen. Full 10 m resolution images of operator designated subareas can be accessed using the *Full res* menu option described below. The primary image for the Novaya Zemlya test site is a 20m resolution SPOT image of the region, which is the highest resolution unclassified image which is currently available. Thus, when running in an unclassified environment, the *Full Res* option is not available in conjunction with the Novaya Zemlya satellite image display. However, when running in a classified environment, selection of *Full Res* option for this test site provides access to a high



- A - satellite image menu buttons
- B - information bar
- C - side menu
- D - current event

resolution, classified NPIC image of the area of interest. In either case, selection of *Satellite Image* from the main FUNCTION menu results in a display of the SPOT image of the designated test site, with the best available locations of previous explosions at that site shown as color-coded square overlays and with the current event highlighted by a yellow diamond.

The different colors are used to differentiate those explosions about which the Soviets have published data in the open literature (blue) from those for which only seismic information is available (red). As can be seen from the display, selections within this module can be made from menu buttons distributed both across the top and down the right side of the display, to initiate various interactions with the image and associated data. These will now be described in order, proceeding from left to right and then top to bottom.

Images

Image selection
Satellite image
Surface topography
Thickness of alluvium
Depth to mesozoic
Depth to paleozoic
Depth to granite

This menu button is used to access the compressed 30 m resolution SPOT image of the selected test site (*Satellite image*) or color-coded representations of other data which have been registered to the SPOT image. For the Shagan River test site these include the DMA topographic data (*Surface topography*), thickness of the surface alluvium (*Thickness of alluvium*) and the depths beneath the surface to the various subsurface geologic units which have been mapped (*Depth to mesozoic*, *Depth to paleozoic* and *Depth to granite*). For the Novaya Zemlya test site, where the subsurface geology is less well known, only the *Surface topography* (DMA) image is currently available. Where appropriate, color scales are displayed with the images, listing numerical values of the displayed variable in meters.

Locations

Location selection
Event locations (SPOT)
Event locations (ISC)
Compare events

The LOCATIONS menu is used to overlay different explosion location estimates on the test site image currently being displayed. The choice of *Event locations(SPOT)* or *Event locations(ISC)* from this menu results in the overlay of the corresponding location estimates for all previous

explosions at that test site. The choice of *Compare events* results in the overlay of the best available locations for just those events for which data are available for a particular seismic phase and station selected using the *Compare* function from the Analyst Station module.

The location symbols can be used to obtain information about the event or to designate the event for further processing. For example, clicking on any location symbol, causes available summary information about the event to be displayed on the information bar.

Overlays

Overlay selection	
Current event	
Surface geology	
Topography contours	
Event magnitude data	✓
Historical magnitude data	✓
Subsurface contours	✓
Location differences	✓
Digitized overlays	✓

The OVERLAYS menu is used to access and view a variety of data which have been registered to the SPOT satellite images of the two test sites. These data can be graphically superimposed on any of the available images and automatically adjust to the scale of the selected image.

Current event

This option overlays the current event location on the displayed image.

Surface geology

This option overlays a graphical representation of the mapped surface geologic features for the selected test site on the displayed image (see Figure 6 of Chapter 2).

Topography contours

The *Topography contours* overlay selection can be used to superimpose a contour representation of the DMA topographic data for the selected test site on either the compressed or full resolution SPOT images or on the color-coded surface topography representation from the IMAGES menu. The contours are labeled with the corresponding values of elevation above sea level in meters (see Figure 7 of Chapter 2).

Event magnitude data

Event magnitude data
Mb residual
Mb - M_{Lg}
Moment tensor
Mb - M_o

Selection of the *Event magnitude data* option generates a pull down menu listing the various magnitude related overlays available for the current event. Magnitudes must have already been estimated for this event before these overlays are accessed. If the required magnitudes are not available for a given selection, a message will appear on the screen stating "overlay file not available." The *Mb residual* option produces an overlay to the displayed image listing the difference between the current event network-averaged m_b value and the m_b value obtained for that event at an individual station specified in the Magnitude Measurement module, plotted at the current event location. Similarly, selection of the *Mb - M_{Lg}* or *Mb - M_o* option produces overlays listing the difference between the current event network-averaged m_b value and a corresponding single station M_{Lg} value (see Figure 20 of Chapter 2) designated in the Magnitude Measurement module, or network-averaged surface wave isotropic moment estimate (M_o), respectively. Selection of the *Moment tensor* option from this menu produces an overlay of a graphical representation of the surface wave moment tensor inversion solution at the current event location (see Figure 26 of Chapter 2). This display consists of two concentric circles enclosing a straight line segment, where the ratio of the diameters of the circles is proportional to the ratio of the isotropic (light blue) and tectonic (yellow) moments and the yellow line segment is oriented parallel to the inferred strike of the tectonic release component.

Historical magnitude data

Historical magnitude data
Mb residuals
Mb - M_{Lg} (NORSAR)
Moment tensor
Mb - M_o

Selection of *Historical magnitude data* from the OVERLAYS menu activates a pull down menu which provides access to overlay representations of previous experience with the various magnitude related parameters corresponding to the current *Event magnitude data* selections which were just described. In this case, selection of *Mb residuals* activates a secondary pull down menu listing the various USAEDS stations for which the previously observed differences between network-averaged and single station m_b values have been contoured as a function of event location within the test site (currently only available for the Shagan River test

site). Similarly, selection of *Mb - MLg (NORSAR)* produces an image overlay of the differences between the network-averaged m_b values and corresponding NORSAR L_g values in either contour (Shagan River) or discrete event (Novaya Zemlya) form. The *Moment tensor* option produces an overlay of graphical representations of all previous surface wave moment tensor solutions for explosions at the selected test site, where the isotropic and tectonic components are represented by dark blue and red circles, respectively, to differentiate them from the corresponding current event solution (see Figure 26 of Chapter 2). Selection of *Mb - Mo* produces an overlay of the differences between the network-averaged m_b and M_0 values for all previous events for which both these magnitude measures are available.

Subsurface contours

Subsurface contours
Thickness of alluvium
Depth to top of mesozoic
Depth to top of paleozoic
Depth to top of granite

The *Subsurface contours* option in the OVERLAYS menu provides the capability to overlay contours of the various subsurface geologic layer thicknesses and depths on a displayed image, generally the corresponding image from the IMAGES menu. The contours are labelled with the corresponding numerical values of the displayed variable in meters.

Location differences

Location differences
Preferred to SPOT
Preferred to ISC
Preferred to Bocharov

The *Location differences* option provides access to a set of mislocation vector overlays consisting of directed line segments pointing from the preferred to an operator-specified set (e.g., *SPOT*, *ISC*) of explosion location estimates. The preferred locations are those which are thought to be most accurate from among those available, which in the classified environment are generally the NPIC photo locations.

Digitized overlays

Digitized overlays
Current overlay
Shagan subdivisions

The *Digitized overlays* option provides access to an extensible list of overlay files which have been generated by the operator using the *Digitize* feature to be described below. If a feature has been digitized from the SPOT image in the current session, it can be overlaid on the displayed

image by selecting *Current overlay* from this menu. The results of any digitizations which have been saved to a permanent file by the operator in previous sessions (e.g., *Shagan subdivisions*) can also be accessed from this menu and overlaid on any of the available images.

Refresh

Refresh parts of picture
Remove overlays
Remove locations
Clear message area

This menu option is used to remove any overlays (*Remove overlays*) or location symbols (*Remove locations*) which are currently superimposed on the displayed image.

Function

Invoke a function
Analyst station
Save overlay
Save revised image

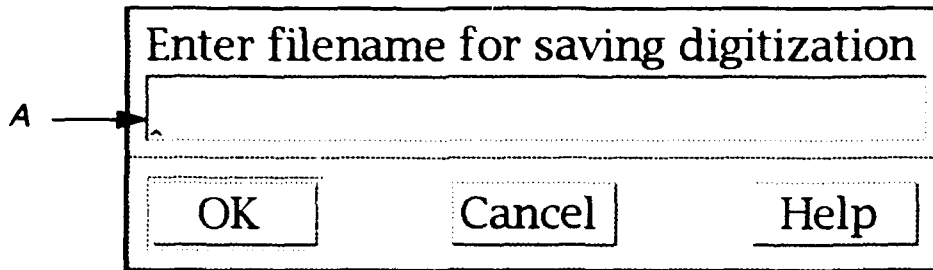
This menu button is used to initiate processes and create permanent overlay files.

Analyst station

Selection of *Analyst station* initiates a process by which seismic waveforms recorded at a specified station from events selected using the side menu *Compare* function described below are retrieved from the database and displayed on the screen in the standard Analyst station format (cf. *Analyst Station* description).

Save Overlay

Selection of *Save overlay* initiates a process by which a digitized overlay can be saved to a permanent file to appear on the *Digitized overlays* menu on all subsequent restarts of the system. This feature is used in conjunction with the *Digitize* button in the side menu. It is implemented through a pop-up menu shown below which allows the operator to click once in the text window, type in a name for the file to be saved (e.g., *Shagan subdivisions*) and then save it to a permanent file by clicking on the *OK* button. If at any time during the process the operator decides against



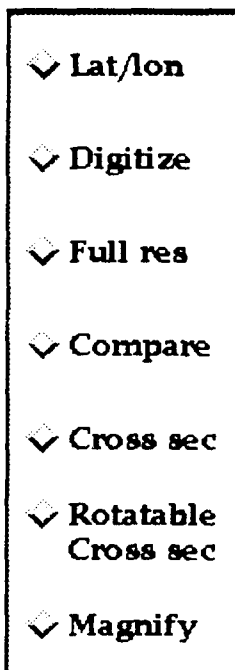
A - text window used to type in a name.

saving the file, the sequence can be terminated by clicking on the *Cancel* button.

Save Revised image

Selection of *Save revised image* initiates a process by which the displayed image is saved with the modified values of contrast and brightness which have been obtained using the side menu *Contrast* and *Brightness* slider adjustments described below. All subsequent displays of this image will employ these revised contrast and brightness values.

Side Menu



The side menu items on the satellite image display provide additional options which permit the operator to interact with the display in a variety of different ways. A notable feature of these buttons is that they initiate processes which remain active while that button is turned on. Consequently, they must be turned off when the associated processing has been completed.

Lat/lon

When this button is highlighted, clicking on any point on the image causes the latitude and longitude of that point to be displayed in the information bar.

Digitize

When the *Digitize* button is highlighted, clicking on any point or a series of points on the image causes the latitude and longitude of the point(s) to be added to a temporary file. When digitization of the selected feature has been completed, the file is closed by clicking on the *Digitize* button again. Any subsequent selection of *Current overlay* from the *Digitized overlays* in the OVERLAYS menu will cause straight line segments to be drawn between these points in the order in which they were selected and overlaid on the image. If desired, this information can also be saved to a permanent named file using the *Save overlay* option from the Satellite Image FUNCTION menu.

Full res

When the *Full res* button is highlighted, in conjunction with the primary SPOT satellite image displays, clicking on a point on the image causes the full 10 m resolution SPOT image data (Shagan River) or high resolution NPIC image data (Novaya Zemlya, classified version only) to be displayed for the area surrounding that point. Once a full resolution image has been displayed, full resolution images of adjacent regions can be accessed by pointing the cursor near the closest border of the display and clicking on the mouse button. To access the full resolution image for a new area not adjacent to the current display, select *Satellite image* from the IMAGES menu and select the new location. Upon completion of the review of the full resolution data, turn off the *Full res* button and proceed.

Compare

When this button is on, events can be selected with the mouse from among those displayed on the image using the *Compare events* option from the LOCATIONS menu. Clicking on any location symbol causes the event location to be highlighted by a diamond and available summary information about the event to be extracted from the database and displayed on the information bar. If, on the basis of this information, the operator decides to select this event, a second click of the mouse button will cause that event

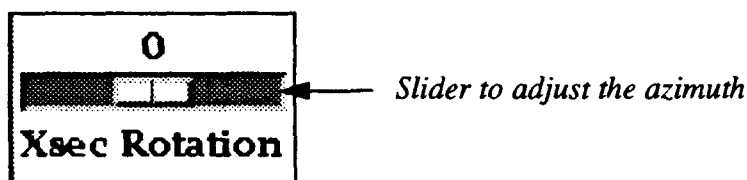
identification label to be added to a temporary file and the highlight diamond will turn white. Additional events can be selected in the same fashion and, upon completion, the file is closed by turning off the *Compare* button. Subsequent selection of *Analyst station* from the FUNCTION menu causes the designated station waveforms corresponding to the selected events in this file to be retrieved from the database and displayed on the screen, with the current event recording at the top and the selected event waveforms below it in the order in which they were selected.

Cross sec

When this button is on, a vertical subsurface geologic section along a line between any two points on the image can be created and displayed by sequentially selecting the points with the mouse. The *Quit* button on the cross section display is used to refresh the underlying image display, from which another cross section can be initiated, or, upon completion, the process can be terminated by turning off the *Cross sec* button.

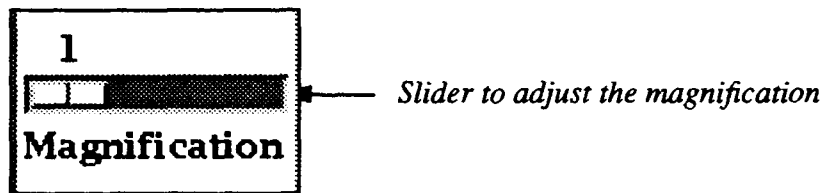
Rotatable Cross sec

When this button is on, a vertical subsurface geologic sections through a specified point can be created and displayed by sequentially selecting any two points with the mouse. The displayed section is centered on the first point chosen and extends in both directions along the azimuth determined by the two points for a distance equal to the distance between the two points. The *Quit* button on the resulting cross section display is used to return to and refresh the underlying image display. Additional cross sections through this same point can then be obtained by interactively modifying the azimuth of the line using the "Xsec Rotation" slider to specify azimuths in the range 0° to 180° (clockwise rotation) or 0° to -180° (counterclockwise rotation). Upon completion, the process can be terminated by turning off the *Rotatable cross sec* button.



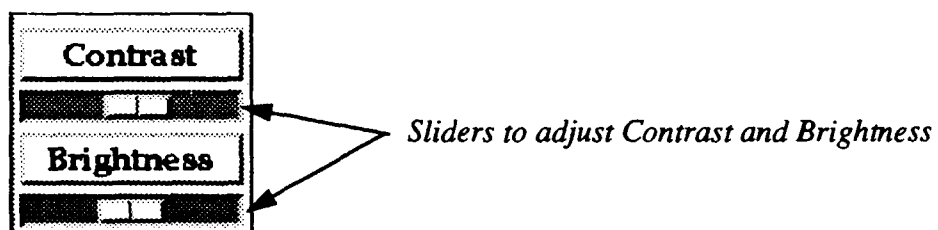
Magnify

When the *Magnify* button is highlighted, clicking on a point on the displayed image initiates a process by which the area surrounding that point can be magnified by the current value of the associated *Magnification* slider. Integral magnification values ranging from 1 to 8 can be selected in this manner. Once a point has been selected, two square boxes will appear on the screen. The first is an empty box of fixed size which surrounds the selected point and outlines the area to be magnified. The second is a cross-hatched or wireframe box appearing at the current mouse location, which outlines the display area for the magnified image. The wireframe can be moved to any convenient place on the screen by simply repositioning the mouse. Clicking on the mouse button then causes the magnified image to be displayed in this window. Selection of the *Quit* button on this display terminates the wireframe window. Different magnified versions of the same scene can be obtained by repositioning the *Magnification* slider, reselecting the point at the center of the area box and repeating the above process. Magnified views of different areas can be obtained by clicking on a new point and repeating the above process. Upon completion, the area box or boxes should be deleted by selecting *Remove overlays* from the *Refresh* menu and then the process can be terminated by turning off the *Magnify* button.



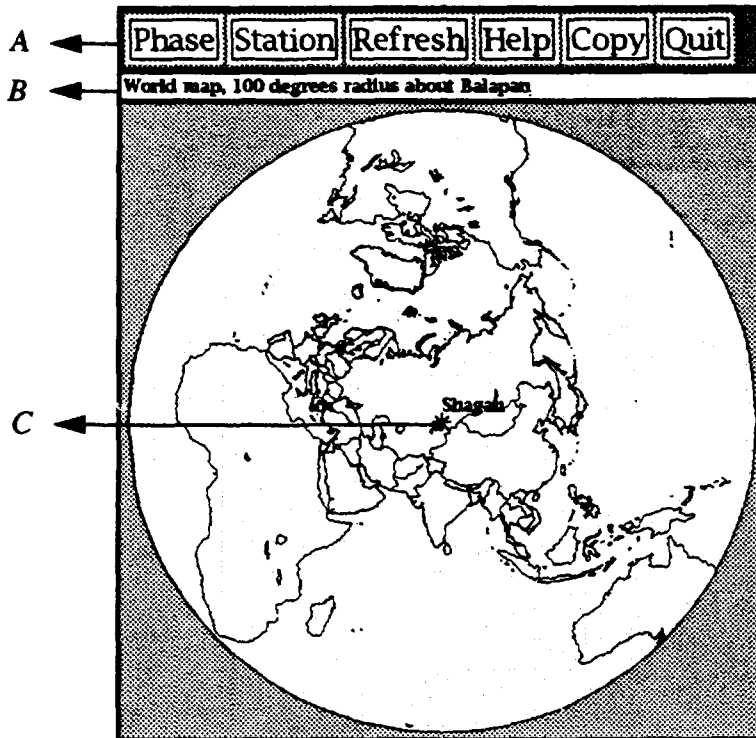
Contrast and Brightness

The slider bars at the bottom of the side menu can be used to interactively adjust the contrast (C) and brightness (B) of the displayed SPOT image. Clicking on the C or B buttons returns the display to the default setting for that parameter.



World Map

This module provides a capability to display the map locations of stations which have recorded digital seismic data for the selected event. The maps are plotted as azimuthal equidistant projections of the globe ($\Delta < 100^\circ$) centered on the selected test site.



A - world map menu buttons

B - information bar

C - current test site

Phase

Phases
Regional P
Lg
Teleseismic P
Rayleigh (vertical)
Rayleigh (radial)
Love

This menu button is used to select the seismic phase for which the database will be searched for stations which recorded data from the current event. The locations of these stations are then automatically plotted on the map display together with the standard three or four letter station abbreviations.

Station

Stations	
Regional P	Lg
Telesismic P	HEA
Rayleigh (vertical)	LARU
Rayleigh (radial)	IGAR
Love	BKIV
	IOBN
	NOLA0
	WMQ

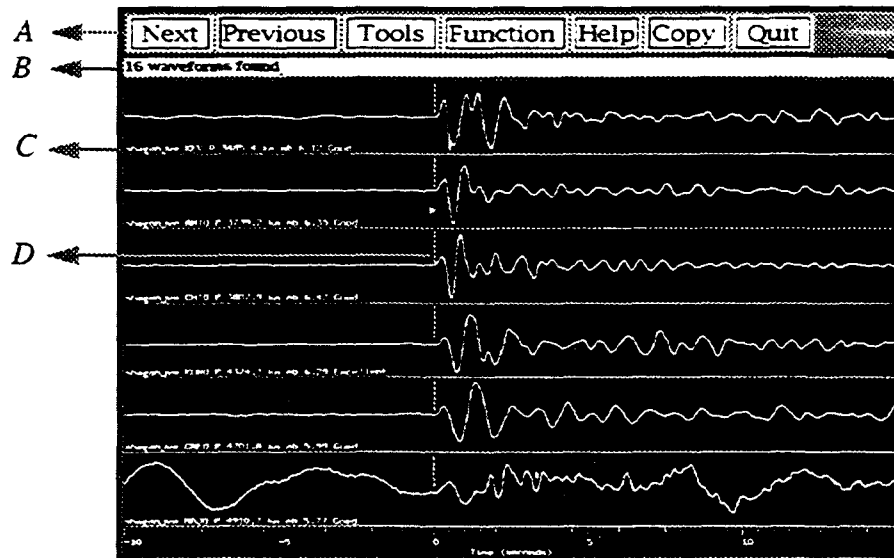
This menu button is used to select a station from among those which have recorded data for the designated phase and event. Selection of a station causes a straight line to be drawn on the map between the test site and the station which, in this projection, corresponds to the great circle path between these two points.

Refresh

This menu button is used to remove the station location overlays from the map display prior to selection of another phase.

Analyst Station

Selection of *Analyst Station* from the main FUNCTION menu following the selection of an event and seismic phase produces a display of the corresponding digital seismic waveform data in a format which permits the operator to interact with them to extract the parametric data required for determination of the various magnitude measures for the current event. The default setting provides for the waveforms to be displayed in order of increasing station epicentral distance, with six waveforms per screen or "page." The mode of display varies with the selected phase, with teleseismic and regional P segments denoted (P and P_n) displayed as a function of time (from 10 seconds before to 15 seconds after signal onset), while the L_g and surface wave segments are displayed as a function of group velocity (10 to 2.5 km/sec for L_g ; 5 to 2.5 km/sec for the Rayleigh and Love phases).



A - analyst station menu buttons

C - waveform information

B - the information bar

D - arrival pick

As is illustrated in the display, each waveform segment is annotated to indicate the event, station, phase, epicentral distance, approximate single station m_b value and a waveform quality assignment which can be interactively set using the TOOLS menu function *Set quality* to be described

below. The vertical line segments on these displays marks the estimated signal onset time which also can be changed interactively using the TOOLS menu function *Pick arrival* to be described below.

Next

This menu button is used to page forward through the waveform displays, six waveforms at a time, in order of increasing station epicentral distance.

Previous

This menu button is used to page backwards from the current display through the available waveforms from stations at smaller epicentral distances.

Tools

Tool selection	
Pick arrival	
Set quality	→
Demean/detrend	
Filter	
New instrument	→
Expand	
mb	
Compare	
Clone	

This menu button is used to access the various signal processing and parameter extraction functions which have been provided to facilitate the evaluation of the displayed seismic data and the determination of the various seismic magnitude measures. Once a selection has been made from this menu, the corresponding function remains active until another choice is made or until a new analyst station is initiated.

Pick arrival

This tool permits the operator to change the estimate of signal onset time by pointing at the location of the new estimate on that trace and clicking once. Prior to analyst review, the default onset times are the predicted Herrin 68 travel times for P and P_n and a group velocity of about 3.5 km/sec for the L_g and surface wave phases. Upon completion of this review, the revised signal onset estimates can be saved to the database using the *Save* feature from the FUNCTION menu described below. Subsequent analyst station displays of these data will then show the revised arrival estimates.

Set quality

Data quality
Excellent
Good
Visible
Invisible
Broken
Interfering
Clipped

Selection of this tool activates a pull down menu listing a variety of quality categories which can be assigned to the displayed data. If no prior analyst assignment has been saved to the database, the trace will be displayed initially with a *Not Checked* label. Assignment of a revised quality can be accomplished by selecting a category from this menu and then clicking on any trace to which that category applies. Category assessments are subject to operator judgment, but generally *Excellent* is associated with apparent signal-to-noise ratios of greater than about five, *Good* with signal-to-noise ratios in the range from about two to five and *Visible* to identified signals with signal-to-noise ratios of less than about two. The last four categories (*Invisible*, *Broken*, *Interfering*, *Clipped*) are generally used to designate data which will not be processed to obtain magnitude estimates. *Invisible* signifies that the displayed data contains no evident signal, while *Broken* indicates an instrument malfunction and *Interfering* denotes contamination of the displayed data by arrivals from a different event. The category *Clipped* is assigned only if that portion of the displayed data containing the phase arrivals to be used in the corresponding magnitude determination shows evidence of clipping. New quality assignments can be saved to the database at any time by using the *Save* feature from the **FUNCTION** menu described below.

Demean/detrend

This tool permits the operator to remove any DC bias or linear trend from traces which are subsequently selected with the mouse. The resulting displayed time series have mean amplitudes of zero.

Filter

This tool permits the operator to bandpass filter (Butterworth) any subsequently designated trace between interactively set low frequency and high frequency limits. These frequency bounds are set with slider bars accessed from a pop-up window (see Figure 14 of Chapter 2), as are the slopes (i.e., pole numbers) of the response roll-off outside the specified

band. When the bandpass filter processing has been completed, the interactive slider window can be cancelled by selecting the *Exit* button.

New instrument

New Instrument	
wwssn	sp
wwssn	lp
sro	sp
sro	lp
aeds	sp
aeds	lp

This tool permits the operator to analytically transform any subsequently designated trace into the trace which would have been observed at that station if the data had been recorded on any one of three standard instruments (i.e., WWSSN, SRO, USAEDS) whose response characteristics are documented in the EFCRES instrument response file at the ARPA Center for Seismic Studies.

Expand

This tool permits the operator to produce a full page display of any subsequently designated trace. For P and P_n , both the amplitude and time scales are expanded, with the displayed time segment extending from four seconds before to six seconds after the estimated signal onset time. For the L_g and surface wave displays, only the amplitude scale is expanded. This feature is most commonly used in conjunction with the m_b tool to facilitate the determination of peak-to-peak amplitude and period of the pulse used to define the single station P wave magnitude value. However, any of the other TOOLS menu functions can be accessed from the expanded display and applied to the data. When processing of the expanded data has been completed, the display can be terminated by selecting the *Exit* button.

m_b

This tool allows the operator to use the mouse to draw a rectangle on a selected trace so as to define the peak-to-peak amplitude and half period of the selected cycle of initial P or P_n motion to be used in the estimation of the corresponding single station magnitude measure. This is accomplished by clicking the cursor at the peak, holding down the mouse and dragging the cursor to the trough of the selected cycle. Upon release of the button the approximate peak-to-peak ground motion amplitude and associated period of the pulse is automatically computed and displayed on

the information line of the analyst station display. After this process has been repeated for each usable trace, the amplitudes and periods can be saved to a file for subsequent input to the corresponding magnitude estimation module using the *Interface file* feature from the FUNCTION menu described below.

Compare

This tool allows the operator to select a trace and initiate a process in which the on-line seismic database is searched for all other events at the selected test site for which data for the displayed phase were recorded at the designated station. A file identifying the events meeting these criteria is then automatically created and used to update the file used by *Compare events* in the LOCATIONS menu of the Satellite Image module. The map locations of these events can then be overlaid on the SPOT satellite image of the test site and the designated station data corresponding to selected events can be displayed and compared to the data recorded at that station from the current event using the *Compare* and *Analyst station* functions from the Satellite Image menus.

Clone

This tool allows the operator to select any displayed trace and create a color-coded (red) copy of that trace which can be dragged with the mouse to any position on the screen to permit detailed comparison with other displayed waveforms (see Figure 16 of Chapter 2). This process is applicable to any P or P_n display or to any analyst station display of compare event data recorded at a fixed station. However, it should be noted that L_g or surface wave recordings from stations at different distances cannot be directly compared in this fashion because they are displayed as a function of group velocity rather than time.

Function

Function selection
Interface file
Save
Restore

This menu button is used to save processing results to temporary (*Interface file*) or permanent (*Save*) files, or to undo (*Restore*) the results of any signal processing which has been applied to the displayed waveforms.

Interface file

The *Interface file* option enables the operator to save any interactively determined parametric data to temporary files which will subsequently be used as input to the appropriate magnitude determination modules. More specifically, once the amplitudes and periods for a particular P phase (P or P_n) have been determined for each usable recording using the m_p function from the TOOLS menu, the results can be saved for further processing by invoking the *Interface file* function.

Save

The *Save* option enables the operator to save any revised determinations of data quality (*Set quality*) and signal onset times (*Pick arrival*) to the permanent database. Once this function has been invoked, any subsequent displays of these same data in the analyst station format will incorporate the revised estimates of these parameters.

Restore

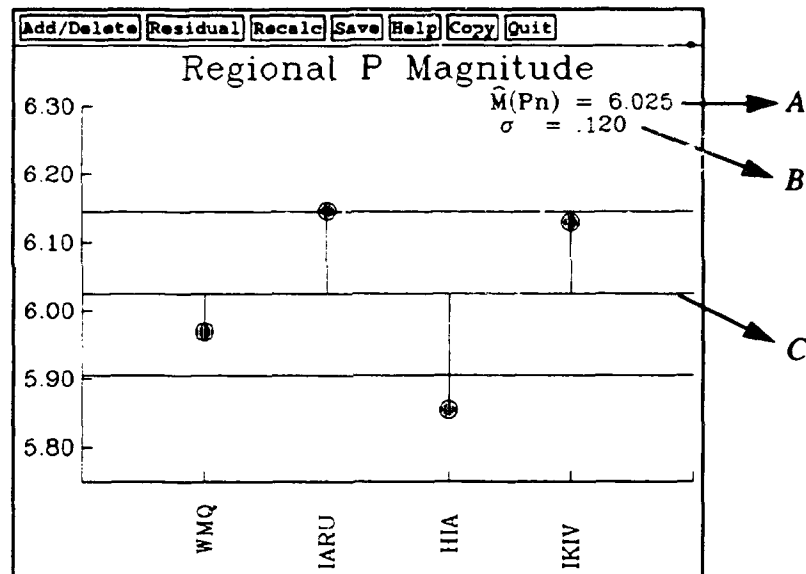
The *Restore* option allows the operator to remove the effects of any filtering or instrument transformations conducted during the current session to return the displayed waveforms to their initial form. However, any revisions to data quality and signal onset estimates made during the current session are retained during this process and, consequently, the *Restore* option can also be used to realign the displayed traces to coincide with any revised signal onset time markers.

Magnitude Measurement

Magnitude measurement
Regional P
RMS Lg
mb
Spectral P
Moment Tensor

This module provides the capability to estimate network-averaged seismic magnitude measures from the waveform and parameter data corresponding to the individual seismic arrivals previously reviewed by the operator using the analyst station module. At the present time, five separate magnitudes based on regional P and L_g waves (*Regional P, RMS Lg*), teleseismic P waves (*mb, Spectral P*) and long-period Rayleigh and Love waves (*Moment Tensor*) can be estimated using this module.

Regional P



A - network-averaged magnitude

B - standard deviation

C - mean magnitude estimate

Used to estimate single station and network-averaged regional P phase magnitudes ($\hat{M}(P_n)$) from the amplitudes and periods which were saved in the corresponding interface file during the analyst station review of the regional P phase data. The resulting display lists the network-averaged magnitude value ($\hat{M}(P_n)$) and the associated standard deviation of the data (σ) and shows the corresponding single station magnitude estimates (filled circles) with respect to the mean and plus and minus 1σ lev-

els (horizontal lines). At the same time, the ($\hat{M}(P_n)$) value is automatically written to a temporary file and is designated as the regional P wave magnitude for the current event. The menu options on this display can be used to interact with and revise this fully automatic solution.

Add/Delete

Selection of the *Add/Delete* option activates a pulldown menu listing the individual stations contributing to the network-averaged magnitude estimate. If the operator wishes to eliminate a station from the average (e.g., because of large deviation from the mean value), highlighting that station name in the menu causes that station to be eliminated from future estimates of the network averaged value. This process can be repeated to delete any number of additional stations.

Recalc

Once a desired subset of stations has been defined through this process, the *Recalc* menu option can be selected to automatically generate a revised magnitude estimate and corresponding display. At any point in this review, an eliminated station can be added back into the averaging process by re-selecting it from the *Add/Delete* station list, at which point the highlight on that station name will be eliminated.

Save

If a preferred value of $\hat{M}(P_n)$ is identified during this review process it can be saved to the current event magnitude file using the *Save* menu option, at which point it replaces the complete network value which was automatically written to this file after the initial calculation.

Residual

Selection of the *Residual* option activates another pull down menu with the same list of stations, any one of which can be selected. This initiates a process by which the difference between the current event network-

averaged m_b value (\hat{m}_b) and the designated station $M(P_n)$ value is computed and added to the *Event magnitude data* overlay menu in the Satellite Image module, where it can be superimposed on the image at the current event location and compared with values of this difference obtained for previous events at that test site (if available). Note that an \hat{m}_b value must have already been estimated for the current event before this option can be exercised.

RMS L_g

This module is used to estimate single station and network-averaged regional L_g phase magnitudes ($M(L_g)$) from the vertical component L_g signals recorded at stations for which the data were found to be usable in the analyst station review process. In computing this magnitude measure, the data are first bandpass filtered in a band which typically extends from about 0.6 to 3.0 Hz and then the peak of the RMS amplitude level of the filtered signal is computed over a group velocity interval extending from about 3.6 to 3.0 km/sec. For array stations such as NORSAR, the $M(L_g)$ value is determined as a logarithmic average of the peak RMS amplitude values at the various array sites. Since this is a computationally intensive process, it is generally run in the background while the operator conducts other tasks. When the process has been completed, an RMS L_g icon will appear on the screen, where it can be activated by the operator at his discretion. The resulting magnitude display and associated functionality are identical to those described above for the Regional P phase module with $M(L_g)$ replacing $M(P_n)$. As with the Regional P phase module, an \hat{m}_b value must have already been estimated for the current event before the RMS L_g *Residual* menu option is exercised.



RMS L_g icon

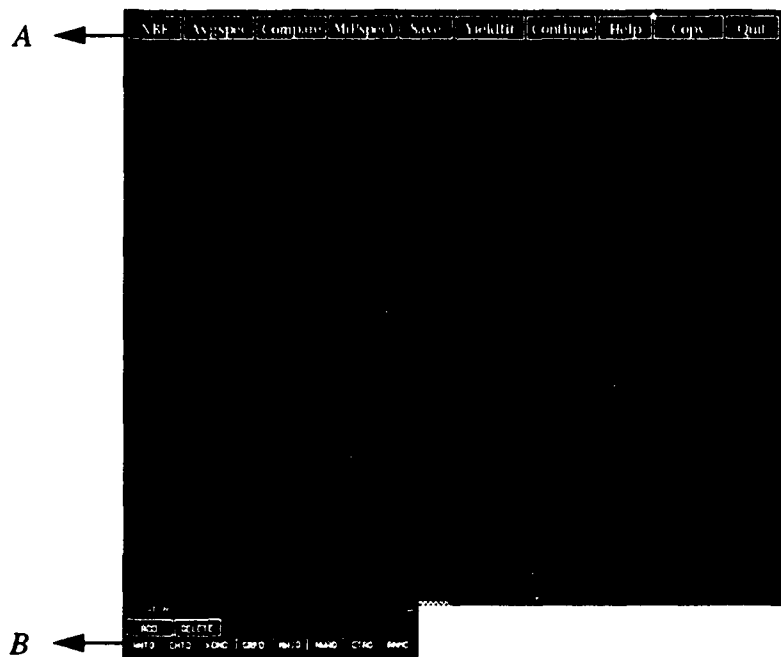
m_b

This module is used to estimate single station and network-averaged teleseismic P wave magnitudes from the amplitudes and periods which were saved in the corresponding interface file during the analyst station review of the teleseismic P phase data. The resulting magnitude dis-

play and associated functionality are identical to those described above for the Regional P phase module with m_b replacing $M(P_n)$. Thus, in the application to m_b , selection of a station from the *Residual* menu initiates a process by which the difference between the current event network-averaged m_b value, \hat{m}_b , and the designated station m_b value is computed and added to the Event magnitude data overlay menu in the Satellite Image module. At the present time, this value can be compared to previous experience only for USAEDS station recordings of Shagan River explosions for which these single station m_b residuals have been contoured as a function of event location within the test site.

Spectral P

This module is used to estimate network-averaged teleseismic P wave spectra and associated spectral P magnitudes ($M(P_{spec})$) and yield estimates through processing of teleseismic P phase data recorded at stations for which frequency dependent station correction factors have previously been estimated through off-line analysis. Once *Spectral P* has been selected from the *Magnitude Measurement* menu, a separate process is ini-

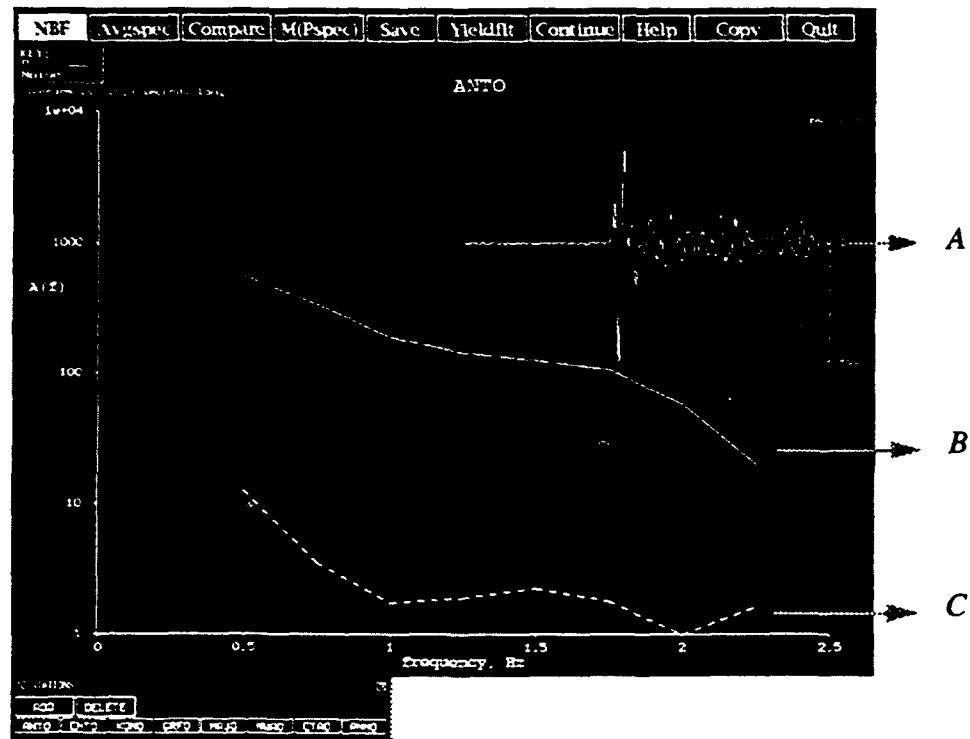


A - Spectral P menu buttons

B - Stations window

tiated with its own display and associated menu. In this initial display, the usable stations for which teleseismic P phase data are available are listed in the Stations window in the lower left hand corner of the display, together with *Add* and *Delete* buttons which can be used by the operator to add or delete stations from the processing stream at any stage. The processing is accomplished by accessing the menu options in the following sequence.

NBF



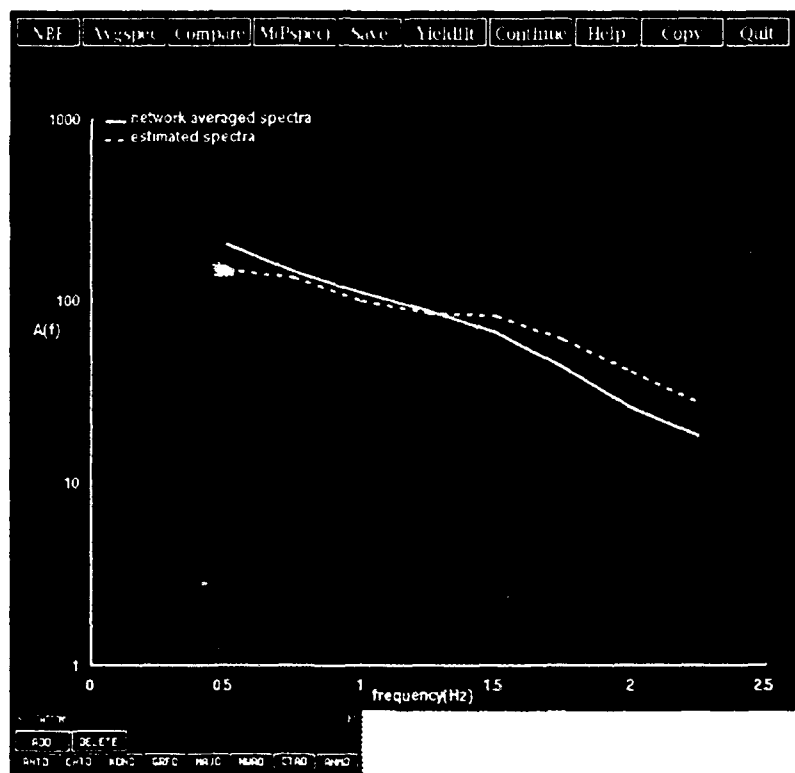
- A - P wave signal
- B - signal spectrum
- C - noise spectrum

This module permits the operator to estimate and display single station P wave signal and noise spectra through narrowband filtering of the waveform data over the band from 0.50 to 2.25 Hz. If upon review of these spectra the operator concludes that the data from a particular station are unusable, that station can be deleted from further processing by sequentially selecting the *Delete* and station buttons from the Stations window. Once the review of the spectra for a given station is completed, selection of

Continue from the menu automatically refreshes the screen and brings up the spectral display corresponding to the next station. When *Continue* is selected following the last station, the NBF function is automatically terminated, signaling the end of the single station processing.

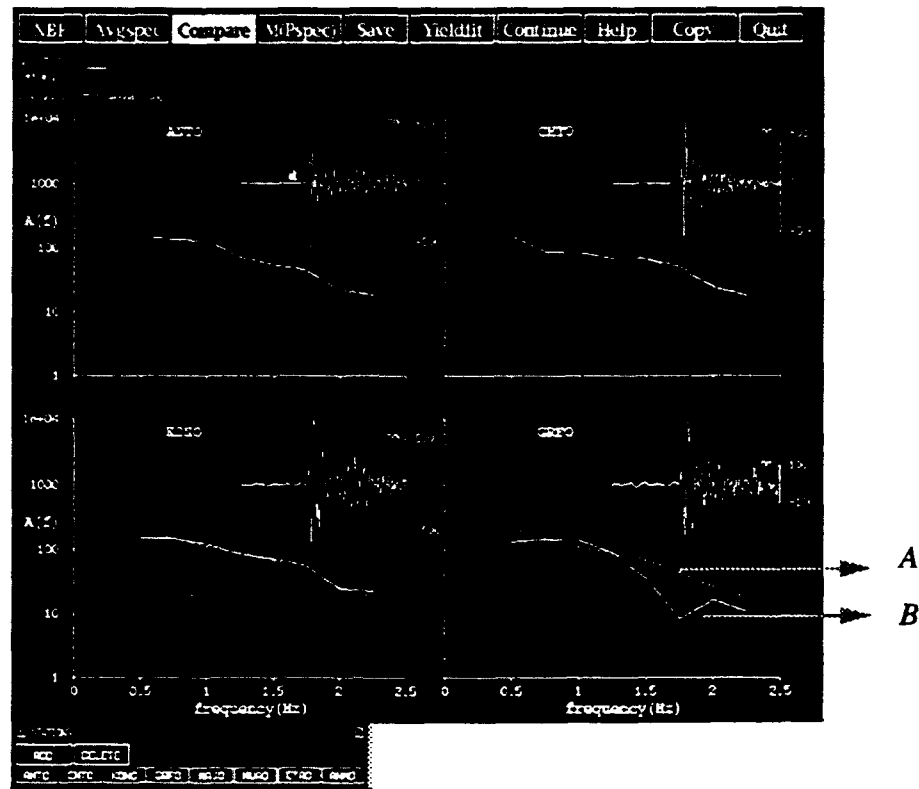
Avgspec

Selection of this menu option initiates a process by which frequency dependent station correction factors are applied to the single station spectra and the resulting spectra are logarithmically averaged to obtain the initial estimate of the network-averaged P wave spectrum for the current event. The result is displayed (solid line) together with the network-averaged spectrum expected, on average, for an explosion of that m_b value on the basis of past experience at that test site (dotted line).



Compare

This module permits the operator to further evaluate the consistency of the spectral data through comparisons of the derived network-averaged spectrum (dotted line) with the individual station-corrected spec-

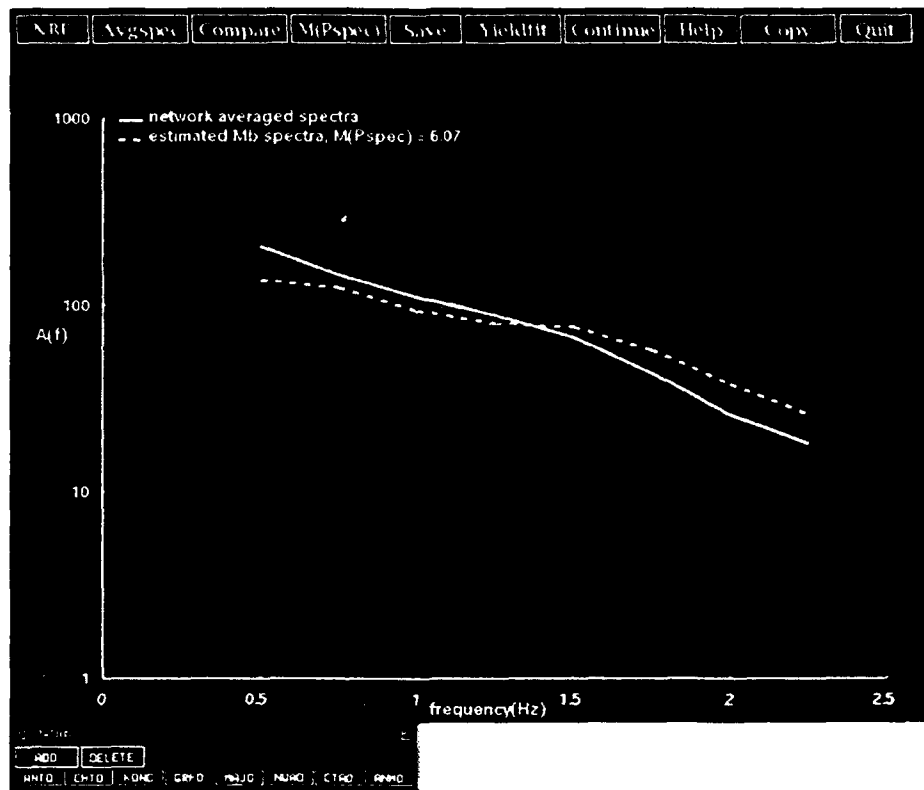


A - derived network-averaged spectrum
B - individual station-corrected spectra

tra (solid lines) which went into the network average. These comparisons are displayed four stations to a page, with subsequent pages accessed using the *Continue* function. During this review, any stations showing significant spectral discrepancies with respect to the average can be eliminated by sequentially selecting the *Delete* and station buttons from the Stations window. When *Continue* is selected following the last station comparison, the *Compare* function is automatically terminated. At this point the operator has the option of returning to the *AvgSpec* function to recompute the network-averaged spectrum without any stations which may have been deleted in the compare process. In the resulting display, the current network-averaged spectrum is shown as a solid line, the previous estimate as a dashed line and the predicted spectrum based on m_b again as a dotted line. This process of deleting (or adding) stations and recomputing the network average can be repeated until a satisfactory version of the network-averaged P wave spectrum is obtained for the event under consideration.

$M(Pspec)$

This module permits the operator to estimate a P wave spectral magnitude, $M(Pspec)$, from the computed network-averaged spectrum. In the accompanying display, the figure shows the comparison between the final version of the observed spectrum (solid line) and the predicted spectrum (dotted line) corresponding to the m_b value which provides the best overall fit to the observed spectrum over the frequency band from 0.5 to 2.25 Hz. This value of m_b is subsequently designated $M(Pspec)$.

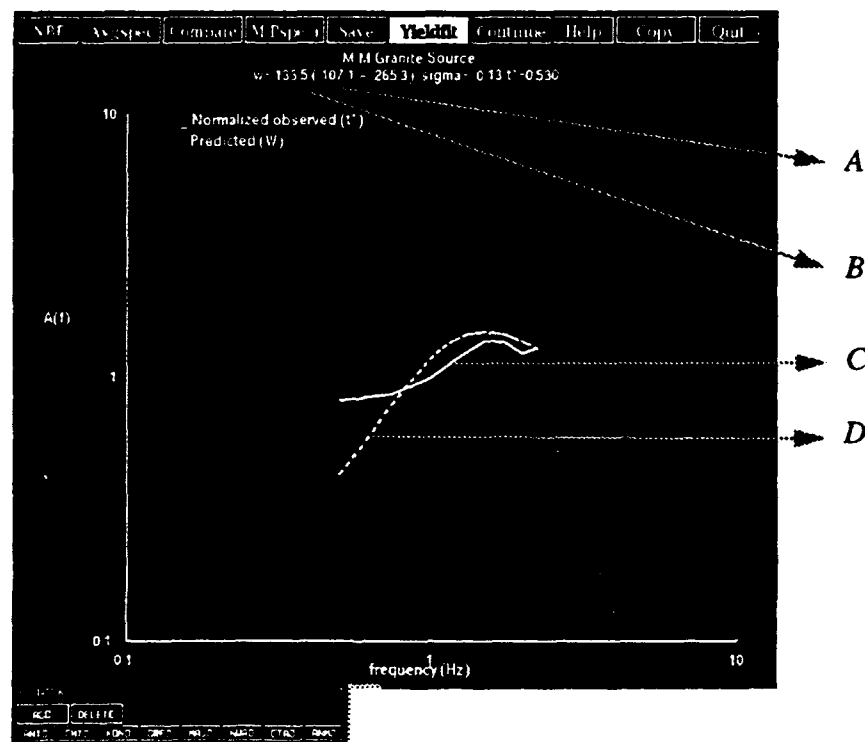


Save

This function can be used by the operator to replace the value of $M(Pspec)$ which is automatically written to the current event magnitude file following the first execution of the $M(Pspec)$ function. That is, if the observed network-averaged spectrum is subsequently modified by adding or deleting stations, the corresponding $M(Pspec)$ value can be substituted into the magnitude file using this menu option.

Yieldfit

Selection of this module initiates a process by which the operator can obtain model-based estimates of explosion yield and pP effects corresponding to the derived network-averaged P wave spectrum for the current event. The initial display shown in Figure 23 of Chapter 2 provides a menu selection of three alternate source models: Mueller/Murphy saturated tuff/rhyolite (M/M Wet Tuff), Mueller/Murphy granite (M/M Granite) and von Seggern/Blandford granite (VonSeg-Blandf). Selection of any one of these three source models produces a display showing a comparison between the attenuation-corrected observed spectrum (solid line) and the predicted spectrum corresponding to the yield which provides the best overall fit to the observations over the band 0.50 to 2.25 Hz (dotted line). This best-fit yield value is listed at the top of the display together with its associated upper bound uncertainty range. Selection of *Continue* then results in a display showing a comparison between the attenuation and source normalized

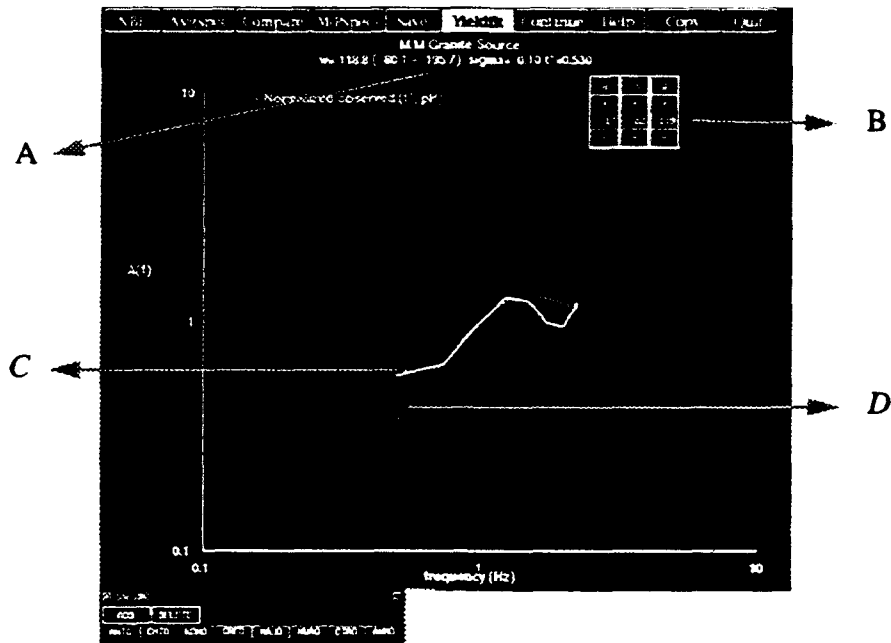


A - upper bound uncertainty range

B - best-fit yield value

C - attenuation-corrected observed spectrum

D - predicted spectrum corresponding to the best-fit yield value



A - modified yield upper bound uncertainty range

B - interactive box used to modify the automatic yield and pP estimates

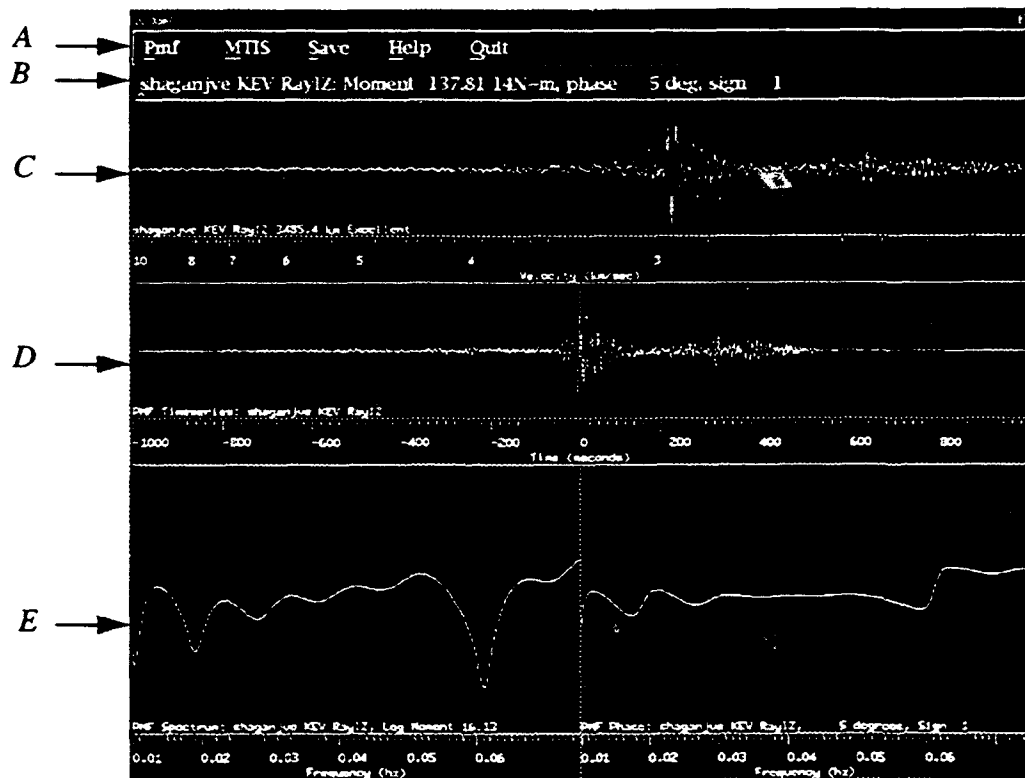
C - final normalized observed spectrum

D - predicted spectrum corresponding to the best-fit yield value

associated predicted spectrum to be automatically updated in the display to reflect this new yield value. By again selecting *Continue*, the operator causes a new pP fit corresponding to this revised source estimate to be determined and displayed. At this stage, the operator can interactively modify the automatically determined pP parameters by selecting the plus or minus buttons under the columns A and T_0 and the display will continuously update to show the comparisons corresponding to these revised parameters. Once the pP model has been finalized, the operator can select *Continue* once again to obtain the spectral comparison display corresponding to the interactively determined yield and pP parameter values. This interactive modification cycle can be repeated indefinitely, thereby allowing the operator to explore a variety of alternative solutions. Once this process has been completed, the operator can select *Quit* to terminate the *Yieldfit* function. At this point, the operator can either select *Yieldfit* again to explore a different source model, or select *Quit* again to terminate the Spectral P processing.

Moment Tensor

This module is used to estimate surface wave moment tensor solutions and associated explosion moment magnitudes (M_0) through processing of the recorded long-period Rayleigh and Love wave data from the current event. Selection of *Moment Tensor* from the Magnitude Measurement menu initiates a phase matched filtering process with associated display and menu. Since it takes some time to initialize this process, it is done in the background and, when completed, an icon appears on the screen which can be accessed by the operator at his discretion to activate the initial phase matched filter display shown below. Proceeding from top to bottom, this initial display contains the menu, an information bar, a standard analyst station display of one component of the surface wave recording from the nearest station, the time history output resulting from applying a phase matched filter (Pmf) to that surface wave recording and finally, at the bottom of the display, the amplitude (left) and phase (right) spectra corre-



A - moment tensor menu

B - information bar

C - waveform window

D - Pmf time history output

E - amplitude and phase spectra

sponding to that Pmf output. The Pmf output time history is plotted as a function of reduced time, computed with respect to the arrival sequence predicted by the estimated group velocity dispersion curve for the propagation path to that station. If the data are good and the estimated dispersion curve is accurate, this trace should be dominated by a narrow pulse centered on zero lag time. The amplitude and phase spectra are displayed as a function of frequency over the band extending from 0.010 to 0.075 Hz (i.e., over the period range extending from about 13 to 100 seconds). The average value of the amplitude spectrum over this range defines the surface wave moment estimate for that station, which is automatically determined by the system and listed in the information line. Ideally, the associated phase spectrum should oscillate around constant values of either 0 or π , denoting normal (sign + 1) or reversed (sign - 1) phase, respectively. More generally, in the automatic processing mode, the phase is defined to be normal if the absolute value of the average phase over this period range is less than $\pi/2$ and defined to be reversed if this quantity is greater than $\pi/2$, and the corresponding value is then listed in the information line. As will be described below, the operator can interactively reset these automatic phase determinations in cases in which the data are ambiguous.

Pmf

Pmf
Pmf
Next
Previous
Auto Pmf
Delete Restore
Change Sign

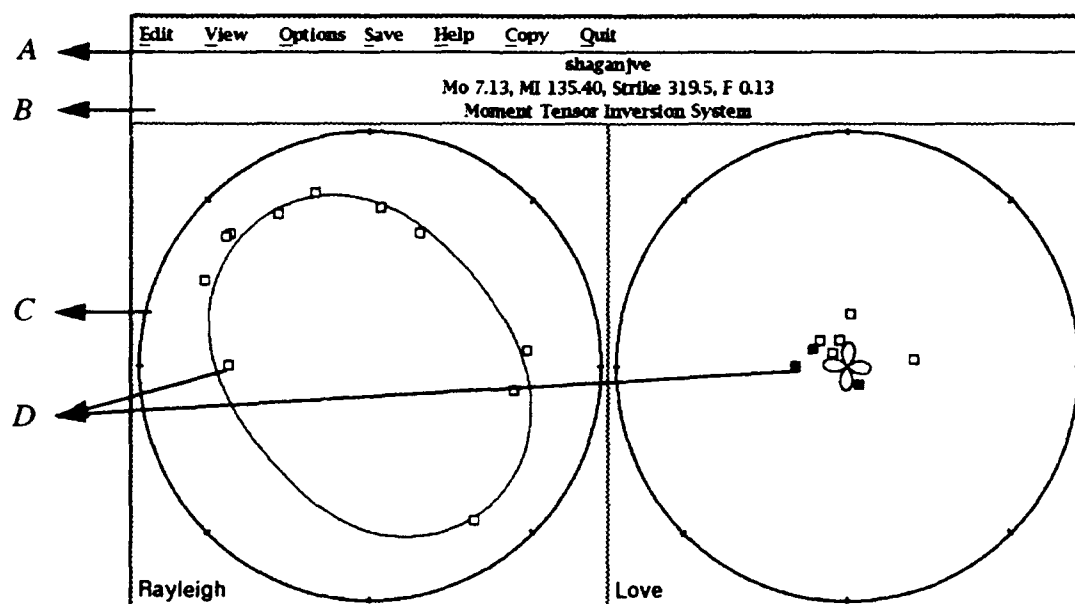
The functions listed under this menu item permit the operator to interact with the displayed surface wave data and associated Pmf results. Selection of the *Pmf* option initiates an automatic process by which the moment and phase corresponding to the displayed waveform are determined and written to both the information line and a temporary file. Selection of *Next* (*Previous*) refreshes the display to show the Pmf results corresponding to the next (preceding) station in the surface wave processing queue. Similarly, selection of *Auto Pmf* initiates a process by which all the usable surface wave data from the current event are automatically processed through the Pmf routine and the results are sequentially displayed on the screen without any operator intervention. Selection of *Delete/Restore* causes the Pmf results for the displayed trace to be either removed or added to the temporary file of processing results (depending on whether it currently is or is not in that file) which is to be used as input to the moment tensor inversion system (MTIS) module. Finally, selection of the

Change Sign option causes the phase assignment for the displayed trace to be reversed (i.e., to either ± 1 , depending on the current setting).

MTIS

MTIS
Run MTIS

Selection of this option initiates a secondary process with associated menu which permits the operator to interactively process the individual station moments and phases determined in the Pmf module. The initial display shows the fit to the Rayleigh (left) and Love (right) wave PMF moment estimates corresponding to the automatic moment tensor solution listed in the information line below the menu. The default solution for the tectonic component corresponds to thrust motion on a fault dipping at 45° and the resulting moment tensor solution is characterized by an isotropic moment (MI), together with inferred strike and F factor estimates for the tectonic component. On these displays, open and closed symbols denote normal and reversed phase observations, respectively. The associated menu items on this MTIS display permit the operator to interact with these data to eliminate questionable points and explore alternate solutions.



A - MTIS menu buttons

B - information bar

C - moment tensor solution

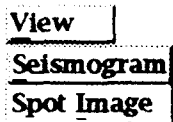
D - single station observations

Edit



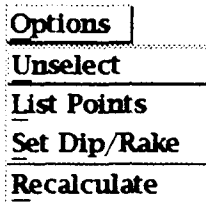
This function permits the operator to select points with the mouse (causing the points to be highlighted) and then to either change their sign or delete them from the inversion input file by selecting the *Change Sign* or *Delete Points* menu options, respectively.

View



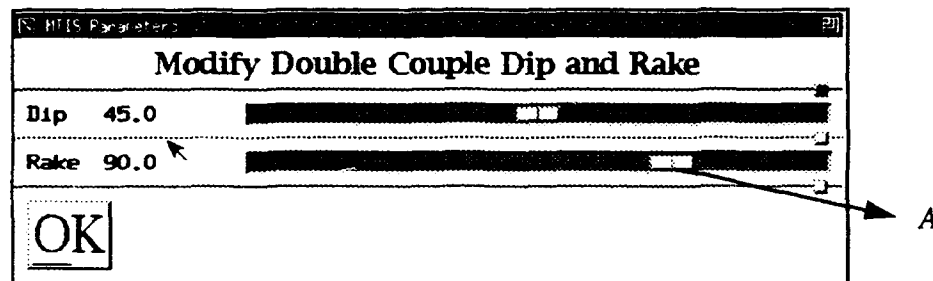
This function permits the operator to either display the seismograms corresponding to stations (points) previously selected with the mouse (*Seismogram*) or to create a graphical representation of the currently displayed moment tensor solution and add it to the *Overlays* menu of the Satellite Image module for display on the SPOT image of the test site (*SPOT image*).

Options



This function permits the operator to undo any previous selection of points (*Unselect*), to modify the dip and rake of the tectonic solution from the default values for 45° thrust (*Set Dip/Rake*) or to recalculate the moment tensor solution to account for any operator specified changes in sign or deletions of points (*Recalculate*).

Selection of *Set Dip/Rake* activates a display of sliders which permit the operator to interactively set the values of these variables to any physically permissible values. Subsequent selection of *Recalculate* from the *Options* menu initiates a display of the moment tensor solution corre-



A - sliders used to adjust dip and rake values

sponding to these revised estimates of the dip and rake of the inferred tectonic solution. When the operator is satisfied that a stable estimate of the moment tensor solution has been obtained, it can be saved to the current event database together with the associated moment magnitude (M_0) using the MTIS *Save* function.

Save

Save

Save to Database

Selection of this Pmf option initiates a process by which the single station moment and phase estimates obtained during the current processing session are saved to the database for subsequent input to the MTIS moment tensor inversion module.

Yield Estimation

This module enables the operator to obtain unified seismic yield estimates and associated uncertainty bounds for the current event by applying a variety of statistical models to the corresponding network-averaged magnitudes. At least one network-averaged magnitude must have already been estimated before this module can be activated. Selection of this option from the main FUNCTION menu produces a display containing a menu and a list of m_b /yield relations (intercept a , slope b) which are currently available for analysis. If the operator wishes to carry out the analysis using one of the listed m_b /yield relations, he may do so by selecting it from the list and then selecting the *Unified Yield* menu option. If he chooses to specify an m_b /yield relation which is not on the list, he must select *New* to initiate an off-line process by which the required input files are generated and the new m_b /yield relation is added to the list.

The screenshot shows a terminal window titled "Please select one of the following:". Inside the window, there is a list of six pairs of values for a and b , followed by the text "AFTAC". Below this list is a "Selection" label and an empty text input box. At the bottom of the window are three buttons: "Unified Yield", "New", and "Help".

Labels with arrows point to specific parts of the interface:

- A** points to the list of a and b values.
- B** points to the "Selection" text box.
- C** points to the "Unified Yield" button.

a	b
4.45	0.75
4.35	0.80
3.65	0.70
4.00	1.00
3.70	0.95
4.20	0.80

AFTAC

Selection

Unified Yield New Help

A - m_b /yield relations

B - selection box

C - menu buttons

Unified Yield

Selection of this menu option following selection of an m_b /yield relation produces a display listing six different statistical models and providing slider bars to adjust the relative weights of the four magnitude measures which currently can be used in the unified yield analysis (i.e., m_b , $M(Lg)$, M_0 , $M(p_{spec})$). These weights must sum to 1.00 and the initial default values provide for equal weighting of all available magnitudes.

*** Unified Yield ***

Model	$m_b(100)$	b	max p
1	5.90-6.00	0.70-0.80	0.50
2	5.90-6.00	0.75	0.50
3	5.95	0.70-0.80	0.50
4	5.95	0.75	0.50
5	5.90-6.00	0.70-0.80	0.70
6	AFTAC		

A ← (points to the table of statistical models)
 B ← (points to the sliders for adjusting weights)

Sliders for: m_b , $M(Lg)$, M_0 , $M(p_{spec})$
 SUM: 1.00

[Help] [Quit]

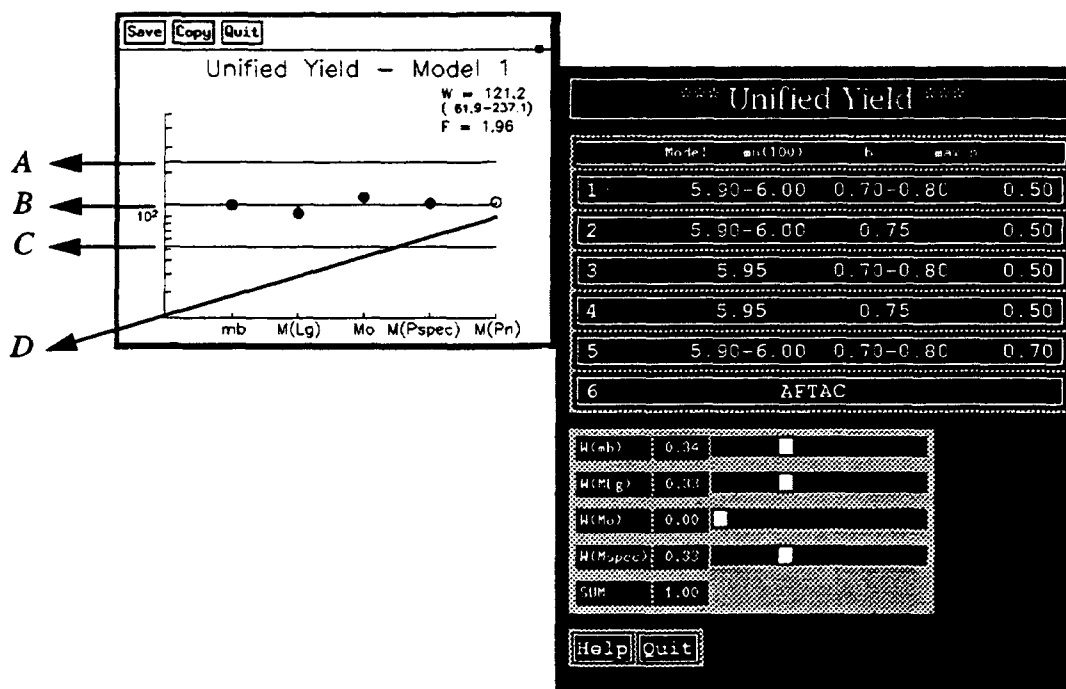
A - statistical models

B - sliders used to adjust the weights

The first five of these models provide unified yield estimates and extremal confidence limits on those estimates corresponding to different sets of constraints on a specified m_b /yield(W) relation, with associated parameters $m_b(100)$, b and max p where $m_b(100)$ denotes the estimated uncertainty in the average value of m_b for explosions with yields of 100 kt, b denotes the estimated uncertainty in the slope of the linear relation between m_b and $\log W$ and max p denotes the upper bound on the absolute value of the correlation of the yield estimation errors associated with the different magnitude measures. The five available models of this type provide estimates corresponding to different values of these three parameters

which are consistent with the current range of expert opinion. Model number 6, labeled AFTAC, provides a unified yield estimate based on m_b and $M(L_g)$ alone, using the current AFTAC standard procedure. When this model is selected, the weights automatically adjust to 0.5 for m_b and $M(L_g)$ and to zero for M_o and $M(P_{spec})$.

Selection of any one of these models generates a display showing the yield estimates corresponding to the individual magnitudes plotted with respect to the unified yield estimate and its associated uncertainty bounds (horizontal lines). Yield estimates determined from magnitude values not included in the unified yield calculation are shown as open circles for purposes of comparison. The unified yield estimate (W) and its associated uncertainty factor (F) are listed in the upper right hand corner of this display together with the yield range corresponding to this F value (in parenthesis). Subsequent selection of models from the menu produce corresponding displays beneath that for the first choice, which remains in place throughout the processing session (See Figure 27 in Chapter 2). When a satisfactory unified yield estimate has been obtained, it can be



A,C - uncertainty bounds

B - unified yield

D - value not included in yield calculation

saved to the current event file using the *Save* option which appears on the menu at the top of each display. Note that the last saved value will be the one which will appear on the *Event Summary* page and in the *Event Report*.

New

This menu option is used to initiate a secondary off-line process by which a new m_p /yield relation can be added to the displayed list of m_p /yield relations available for unified yield analysis. Selection of *New* results in the generation of a pop-up window containing sliders which can be used to set the slope and intercept corresponding to the new m_p /yield relation. Selection of the *Run* option from this display then initiates an off-line process which will run for about 20 minutes to generate the input files required to implement unified yield estimation with this new m_p /yield relation. Alternately, the operator can select the *Exit* option from this display and terminate the pop-up window without initiating a new calculation. If a new calculation is initiated, the operator may continue with the event analysis while the process is running in the background. Re-selection of *Yield Estimation* from the main FUNCTION menu following the completion of this calculation will result in the display of an updated list including the new m_p /yield relation which can then be selected for unified yield analysis.

.75	
Slope	<input type="text"/>
4.45	
Intercept	<input type="text"/>
Exit	Run

Sliders to adjust the slope and intercept.

CORRTEX Yield

This module provides the capability for the analyst to enter a CORRTEX yield estimate for the current event, if such an estimate is available. It is implemented through the pop-up dialog box shown below, which allows the operator to enter the yield estimate via a slider and to then save that value to a permanent file by clicking on the *Save* button. This CORRTEX yield estimate will then appear on all subsequent displays of the *Event Summary* page.

Save Help Quit

Set CORRTEX yield by using the slider, save with the "Save" button.

The CORRTEX yield is set to 100 kt.

100

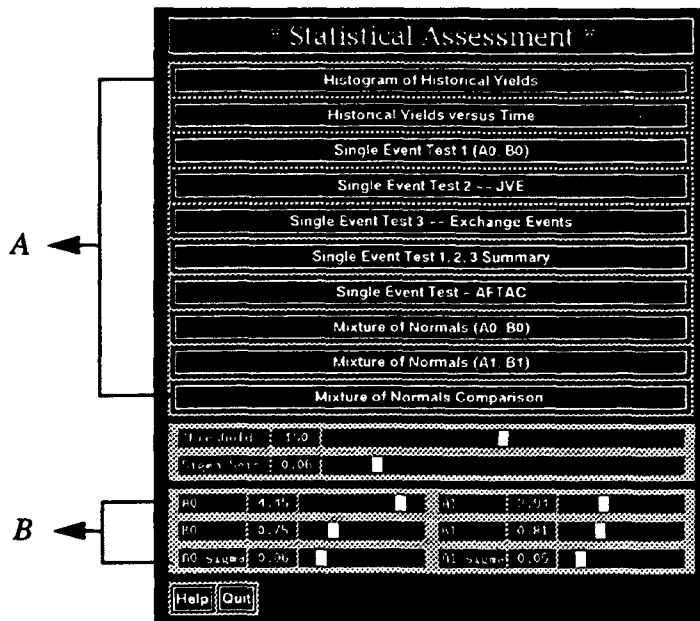
A ←

Corrtex Yield (kt)

A - slider to adjust the yield

Statistical Summary

This module provides access to a variety of statistical tests and displays which can be used by the operator to evaluate the yield estimate for the current event in the context of past experience at that test site and to assess whether this estimate is consistent with an interactively specified yield threshold level (e.g. the 150 kt threshold of the Threshold Test Ban Treaty (TTBT)). A unified yield estimate must have already been determined for the current event before this module can be activated. Selection of this option from the main FUNCTION menu produces a menu display listing the available choices of statistical displays and tests, and providing three sets of slider bars which can be used to vary the yield threshold and the m_y /yield relations used in the computations. The initial default value of the yield threshold is the 150kt level of the TTBT with an associated seismic magnitude uncertainty (*Sigma Seis*) of 0.06. The slider bars at the lower left of the display determine the m_y /yield relation to be used in all tests except the second *Mixture of Normals* test. The initial default values for the intercept (AO), slope (BO) and intercept uncertainty (AO sigma) correspond to the m_y /yield relation used previously in the unified yield estimation module and these values should be used for any single event compliance tests. The sliders can be used to interactively vary the m_y /yield



A - statistical tests

B - slider bars used to set the m_y /yield relation

relation to be used in the histogram and first Mixture of Normals displays of the historical data. The slider bars at the lower right of the display determine the m_b /yield relation for the second Mixture of Normals calculation and have default values consistent with the nominal m_b /yield relation for explosions below the water table at the Nevada Test Site (i.e., $A1 = 3.94$, $B1 = 0.81$ and $A1 \text{ sigma} = 0.06$).

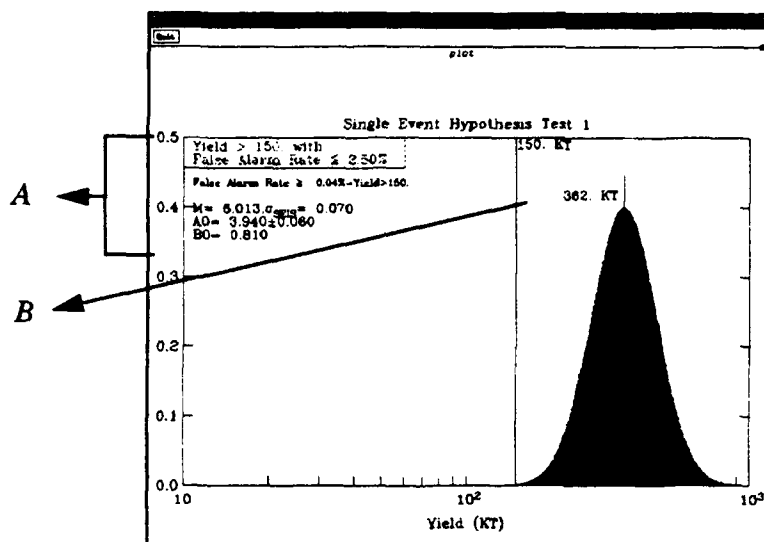
Histograms

Selection of either of the first two menu items, *Histogram of Historical Yields* and *Historical Yields versus Time*, results in displays showing the unified yield estimate for the current event relative to previous experience at that test site, as a function of yield and date, respectively.

Single Event Tests

The various single event tests provide access to formal compliance assessment tests which can be used to make quantitative statements about the probability that the current event is or is not seismically compliant with the specified yield threshold level. *Single Event Test 1(A0,B0)* assumes that only indirect, seismic estimates of the m_b /yield relation are available and utilizes the specified values of $A0$ and $B0$ in estimating the compliance probability. For Shagan River explosions, *Single Event Test 2--JVE* can be accessed to factor in the calibration results from the JVE CORTEX yield determination and utilizes a modified $A0$ value which accounts for this additional information in the test of compliance. Similarly, *Single Event Test 3--Exchange Events* for Shagan River explosions incorporates the announced yields for the JVE exchange events into the estimation of the $A0$ value used in the compliance assessment. The *Single Event Test -- AFTAC*, on the other hand, employs the current AFTAC m_b /yield relation and associated unified yield estimate to assess seismic compliance of the current event with the specified yield threshold based on just the m_b and $M(L_g)$ magnitude measures.

Selection of any of these single event tests results in a display showing the distribution function associated with the current event unified yield estimate in relation to the specified yield threshold. In this representa-

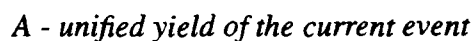


A - compliance assessment results

B - unified yield estimate

tion, the number at the peak of the distribution corresponds to the unified yield estimate and the red shaded area under the curve provides a measure of the probability that the true yield exceeds the specified threshold. The formal compliance assessment results are presented in tabular form in the upper left hand corner of this display. Here, the uppermost box provides a summary of the results of the hypothesis test and indicates whether the current event yield is or is not greater (at the 95% confidence level) than the specified threshold at the nominal false alarm rate of 2.5%. The first line below that box indicates what false alarm rate would have to be accepted to be able to conclude that the true yield of the current event is greater than the threshold yield. The lines below that list the unified magnitude (M) and associated uncertainty (σ_{SEIS}), and the intercept (AO) and slope (BO) of the m_T /yield curve used in the compliance calculation. The final version of *Single Event Test 1* should be saved to the database by clicking on the *Save* button in the associated display. Once saved, the result of this test will appear on subsequent displays of the Event Summary page.

The Mixture of Normals tests (*Mixture of Normals(A0,B0)* and *Mixture of Normals(A1,B1)*) provide more formal means of comparing the unified yield estimate of the current event with the distribution of yields of previous explosions at that test site. In this case, it is assumed that the yields of previous explosions are clustered around a few discrete values and their joint distribution is represented as a superposition of normal distributions, the number and means of which are estimated by applying formal statistical criteria. This test can be run using either the (A0,B0) or (A1,B1) definitions of the m_p /yield relation. In either case, the resulting display shows the unified yield of the current event (*) with respect to the specified threshold and the best-fitting mixture of normals solution for the historical data, where the yields of the individual distributions in the solution are listed beside their respective peaks. The tabular data in the upper left hand corner of the display lists the m_p /yield parameters, number of historical events and individual distribution σ values used in the mixture of normals calculation. If both Mixture of Normals tests have been run, selec-



tion of the *Mixture of Normals Comparison* option results in a similar display in which color-coded representations of the mixture of normals solutions corresponding to both the (AO,BO) and (A1,B1) m_p /yield relations are shown in relation to the current event yield estimate and the specified yield threshold.

Spreadsheet

This module provides a less formal environment for evaluating the seismic yield estimate for the current event in the context of the results obtained from analyses of previous explosions at that test site, as well as any available independent yield calibration data (e.g., CORRTEx). Selection of this option from the main FUNCTION menu produces a display listing the four individual seismic yield estimates (based on m_b , $M(L_g)$, M_0 , $M(p_{spec})$) and corresponding unified yields ($W(Unif)$) for selected explosions at the designated test site. The current event yield values appear as a separate line in the center of the display, while the corresponding values for previous explosions at that test site appear below that line in a scrollable window. For explosions at the Shagan River test site, available calibration yields, including the JVE CORRTEx value, the JVE exchange yields and the yields published in the open literature are listed in the column labeled $W(Calib)$. The corresponding ratios of unified seismic yield estimates to calibration yield values are listed in the column labeled W_u/W_c and the

Change Help Quit

Magnitude/Yield Equations:

Parameter	M_b	$M(L_g)$	M_0	$M(p_{spec})$
Slope	0.750	0.750	1.000	0.750
Intercept	4.470	4.470	5.000	4.480
Weight	0.250	0.250	0.250	0.250

Current event:

Date	$M(M_b)$	$M(M(L_g))$	$M(M_0)$	$M(M(p_{spec}))$	$M(unified)$	$M(calib)$	Source	$M(u)/M(c)$
09/14/88	113.414	99.083	135.519	115.188	115.798			

Other events:

Date	$M(M_b)$	$M(M(L_g))$	$M(M_0)$	$M(M(p_{spec}))$	$M(unified)$	$M(calib)$	Source	$M(u)/M(c)$
11/30/88	123.976	125.122		167.647	118.914	125.000	Bocharov	0.961
11/02/72	179.188	157.519		233.346	180.021	165.000	Bocharov	1.152
12/10/72	127.840	146.780		114.113	129.578	140.000	Bocharov	0.926
01/15/66	83.178			86.563	84.800			
07/23/73	202.613	198.526		219.448	207.186			
12/14/73	80.662	72.666		83.290	72.206			
06/11/78	80.662	50.894	128.825	88.760	82.785			
08/28/78	94.045	112.720	81.283	92.045	95.023			
09/15/78	83.176	82.667	112.202	85.245	90.823			
11/29/78	113.066	99.694	120.228	98.679	107.416			
06/23/79	173.780	130.217	177.828	168.526	162.588			
07/07/79	85.770	99.388	75.858	88.716	87.433			
08/04/79	131.826	149.509	186.209	166.981	158.831			
08/18/79	144.544		104.713	135.519	128.259			
10/28/79	109.648	129.420	194.984	104.072	134.531			
12/02/79	94.046	84.723	138.038	96.879	103.321			
12/23/79	158.489		79.433	149.509	129.144			
09/14/80	226.229		213.796	194.685	214.904			
08/13/81	120.227	155.587	181.970		152.598			
10/18/81	100.000	104.392	144.544		116.312			

Summary of statistics:

Given 3 calibration events:

Average Unified Yield/Calibration Yield ratio: 1.010

F factor: 1.263

A - magnitude yield parameters

B - current event yield values

C - yield estimates

logarithmic average value of this ratio is listed at the bottom of the display as the average ratio, together with the estimate of the 95% bound on the observed ratios (F factor). Operator interaction with this spreadsheet display is restricted to the top three rows of entries specifying the magnitude/yield relations (Slope, Intercept) for each magnitude type and the relative weight (Weight) to be applied to each magnitude in the determination of the unified yield. Default values for the slopes and intercepts are 4.45 and 0.75, respectively, for m_b , M_{Lg} and M_{Pspec} and 5.00 and 1.00 for M_o . The default values for the weights call for equal weighting of the four magnitudes and, however they are subsequently changed by the operator, it is necessary that they sum to 1.00.

Change

Change	
Change Parameters	
Weights	
M_b magnitude/yield	
M_{Lg} magnitude/yield	
M_o magnitude/yield	
M_{Pspec} magnitude/yield	

Slopes, intercepts and weights can be modified using the *Change* menu option. Selection of *Weights* from this menu brings up a set of four sliders which can be used to redefine the weights to be assigned to each of the individual yield estimates in the computation of the unified yields. Once the new weights are set, the spreadsheet display can be updated by clicking on the *Apply* button.

Select weights for the various magnitude components

Sum of weights = 1.00

A ←

.25

B ←

.25

C ←

.25

D ←

.25

M_b

M_{Lg}

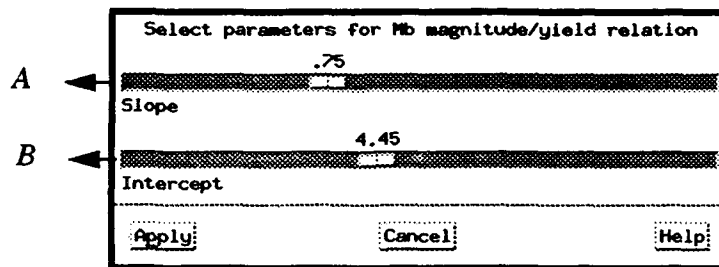
M_o

M_{Pspec}

Apply
Cancel
Help

- A - slider to adjust the weight assigned to M_b
 B - slider to adjust the weight assigned to M_{Lg}
 C - slider to adjust the weight assigned to M_o
 D - slider to adjust the weight assigned to M_{Pspec}

Selection of any one of the four magnitudes from the *Change* menu brings up a pair of sliders which can be used to interactively modify the slope and intercept values to be used in estimating the yields corresponding to that definition of magnitude. Again, once these magnitude/yield parameters have been reset, the spreadsheet display can be updated by clicking on the *Apply* button. Any of the *Change* modules can be exited without modifying the spreadsheet display by clicking on the *Cancel* button.



A - slider to change the slope

B - slider to change the intercept

Event Summary

This module provides a one page summary of the results obtained by applying the YES to the digital seismic data recorded from the selected explosion. Listed results include the date, origin time and location of the explosion, the derived unified seismic yield and its associated uncertainty, the results of the statistical test of compliance of the current event with the 150 kt limit of the TTBT, a tectonic release characterization of the event based on the surface wave moment tensor analysis and, if available, the CORTEX yield estimate for the explosion. In addition, each of the estimated seismic magnitudes is listed together with its associated yield estimate and assigned weight in the determination of the unified yield estimate.

The screenshot shows a window titled "Event Summary" with a menu bar containing "Copy", "Help", and "Quit". The window is divided into two main sections. Section A, indicated by an arrow, contains event information: Test Site (Shagan), Date (14 September 1988), Origin Time (4:0: 0.00 UT), Location (49.8788N, 78.8225E), Date of Analysis (Sep 29, 1992), Unified Seismic Yield (116.5 KT), CORTEX Yield (Not available), Unified Seismic Uncertainty (F = 1.55 (75.0 kt < M < 180.9 kt)), Threshold Assessment (Accept the null hypothesis that the yield is less than 150kt (2.5% significance level test)), and Tectonic Characterization (F = 0.13, Strike = 319 degrees). Section B, indicated by an arrow, contains a table of measurements used for the conclusions.

Test Site : Shagan
Date : 14 September 1988
Origin Time : 4:0: 0.00 UT
Location : 49.8788N, 78.8225E

Date of Analysis : Sep 29, 1992

Unified Seismic Yield : 116.5 KT
CORTEX Yield : Not available
Unified Seismic Uncertainty : F = 1.55 (75.0 kt < M < 180.9 kt)

Threshold Assessment : Accept the null hypothesis that the yield is less than 150kt (2.5% significance level test)

Tectonic Characterization : F = 0.13, Strike = 319 degrees

The conclusions presented above were based on the following measurements:

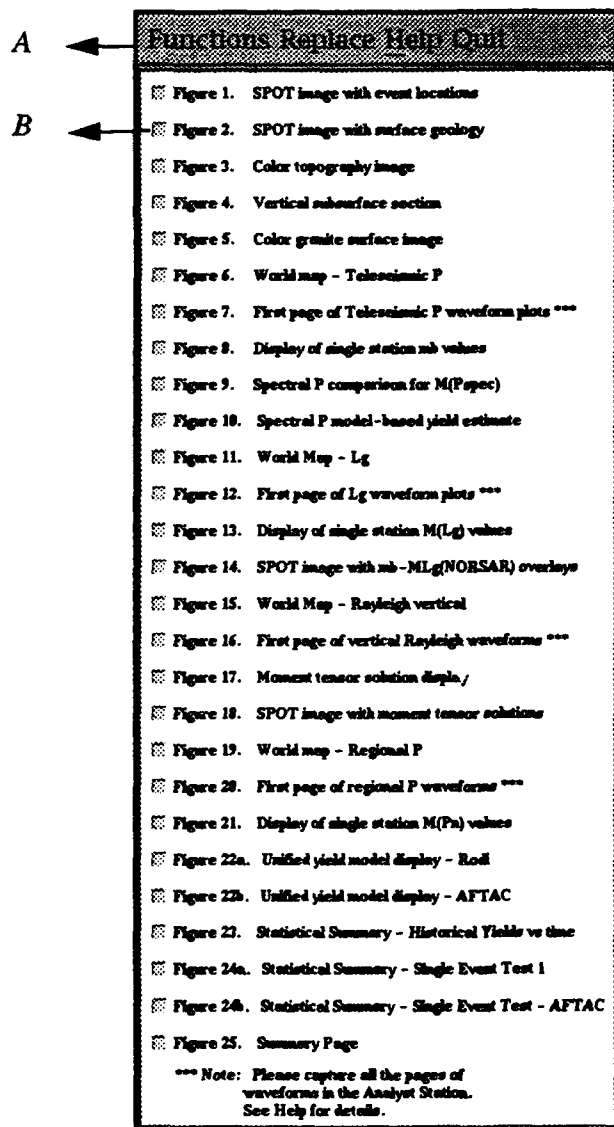
Measurement	Yield	Magnitude	Rel.Weight
mb	120.500	6.011	0.340
M(Lg)	105.900	5.967	0.330
M(o)	136.500	7.132	0.000
M(PSpec)	123.900	6.026	0.330
M(Pn)	125.600	6.025	0.000

A - event information

B - summary of results

Event Report

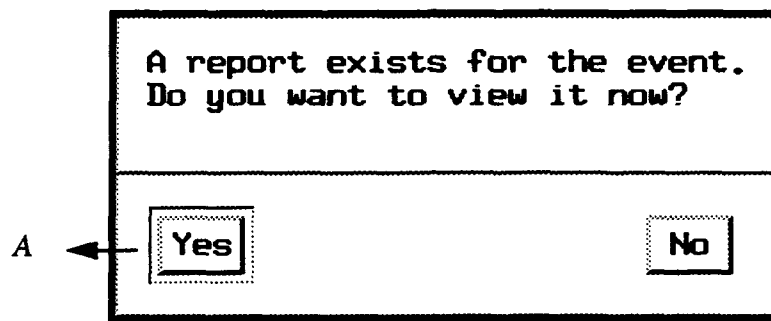
This module is used to generate a color report for an event which has already been analyzed using the procedures specified in the user's manual to obtain seismic magnitude measures and corresponding yield estimates. The report consists of figures which are selected by the user with the help of this module and automatically generated text which includes current event parametric data (e.g., location, origin time, magnitudes, yields, test results, etc.) calculated during the analysis of the event. The figures, text and data are integrated into a single FrameMaker document. (FrameMaker is a desktop publishing software package). It follows that the FrameMaker software package (X version 3.0 or later) must be available on the system in order to produce a report using this module.



A - report module main menu

B - toggle button

When *Event Report* is selected from the main *FUNCTION* menu following selection of a test site and an event, a display is produced listing the menu options and the specific figures which must be selected to complete the report for this event. Note that this list of figures and the associated report automatically adjust to the test site and event selected and to the availability of different seismic phase data for the selected event. If a report has previously been generated for the selected event, a pop-up window will appear notifying the operator of that fact and offering the options to either view that previous report (Yes) or to continue (No).



A - Click on Yes button to view the report

If the operator chooses to view the existing report, a FrameMaker window containing the report pops up and the report can then be viewed and modified using the editing tools described under *View Report* option of the *FUNCTIONS* menu. If a complete report does not already exist, the operator must proceed to access and copy the required figures in the order specified on the displayed figure list. Detailed instructions for copying these figures may be found under the *Copy Figures* option under the *HELP* menu in this module. In cases in which some figures have already been copied in a previous session, the square indicators to the left of the corresponding figure numbers in the list will appear filled. The operator should then begin copying figures starting with that listed beside the first unfilled square indicator. The figures required for the event report are acquired by accessing the specified display from the main *YES* menu while the *Event Report* module is running and then selecting the *Copy* button located at the top of that display. As the figures are acquired, the square indicators to the left of the corresponding figure numbers in the menu list will appear filled.

Functions
Generate Report
View Report
Save Report
Print Report
Close Report

Functions

This menu button is used to access the functions required to generate, view, edit and print the report.

Generate Report

Selection of this option initiates an automatic process in which the report text and interactively selected figures are integrated into a FrameMaker document. If a report already exists for this event, a pop-up window will appear notifying the operator of this fact and offering the options to either replace the old report with the current version (Yes) or to cancel the command (No).

View Report

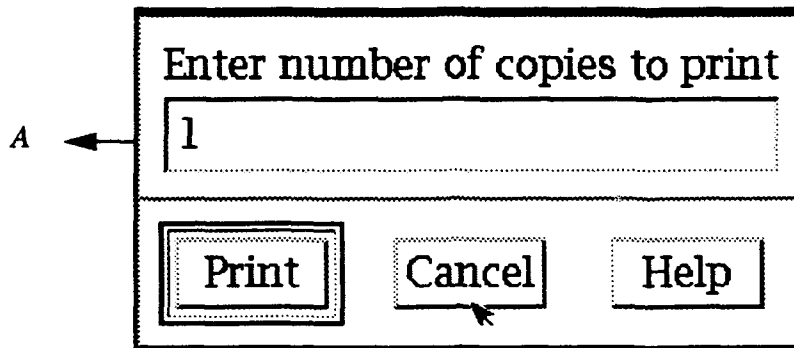
Selection of this option causes a FrameMaker window containing the report to pop-up from which the report can be viewed and edited. The vertical arrows along the bottom edge of this display can be used to page forward (↑) or backward (↓) through the report. Additional text (e.g., event specific comments) can be inserted by simply positioning the cursor at the desired location, clicking once and then typing the desired text. Similarly, text deletions and corrections can be accomplished by positioning the cursor after the word to be deleted, clicking and backspacing. The text is automatically reformatted to accommodate such inserts or deletions. The report must be saved using the *Save Report* option to make any changes permanent.

Save Report

Selection of this option causes the current version of the report to be saved in a file for future access. If a previous version of the report already exists, it will be replaced by the current version.

Print Report

Selection of this menu option causes a dialog box to pop-up which contains a request for the user to enter the number of copies required. To enter a value, click once in the text window and type the number of copies. Selection of the *Print* button then causes that number of copies to be printed on the default printer. Note that for use with this version of the system, this must be a Postscript printer. The dialog box can be exited without printing by selecting the *Cancel* button.



A - Enter number of copies to print here

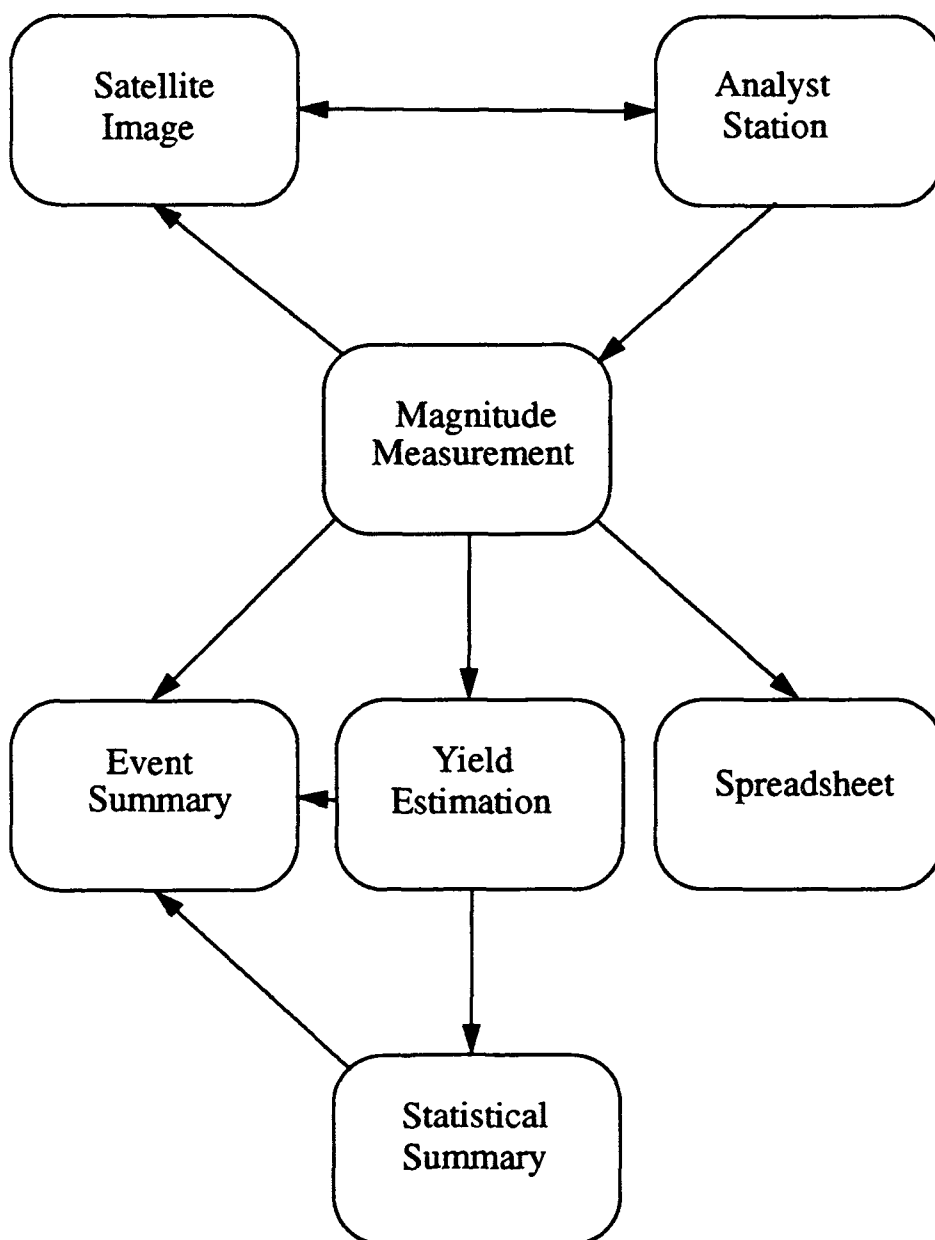
Close Report

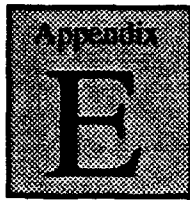
Selection of this option closes the report and terminates the Frame-Maker window. If the operator attempts to close a report before saving it, a pop-up window will appear notifying the operator that any changes he has made to the report in this session have not been saved and offering him the options of either saving the current version at this time (Yes) or of ending the session without modifying the existing version (No).



Dependencies between YES modules

The following chart shows the main modules of YES and their interdependencies.





Adding Data to YES

A separate program has been developed for adding new events and new seismic data to YES via a graphical user interface. In the current configuration, the new events must be explosions at either the Shagan River or Novaya Zemlya test sites. It is assumed that, prior to the initiation of this program, the new seismic data and a wfdisc file describing the data have been assembled in a subdirectory under the \$WFPATH environment variable. For example, if "WFPATH" is defined to be "/usr/data", then the subdirectory might be "/usr/data/shagan/1992101", where, in this hypothetical example, the new event has been designated as an explosion which occurred at the Shagan River test site on the 101st day (i.e., April 10) of 1992. This directory should contain the raw waveform and wfdisc files for the new event. The formats of these required files are described in detail in the ARPA Center for Seismic Studies (CSS) database document entitled "Center for Seismic Studies Database Structure Version 2.8" (Brennan, 1987).

Starting the Program

After the directory containing the .wfdisc and waveform files has been moved to the proper location, the program to add data to the YES database can be initiated by doing the following:

1. **Change to the YES directory.**
2. **Type 'source Init'.**
3. **Type 'Database'.**

Main Menu

The main menu provides access to the various modules which have been implemented to facilitate the addition of new data to YES. It consists

of six menu buttons, together with a template which itemizes the various parameters which can be used to characterize the explosion which was the source of the new data. Selection of any of the new menu buttons causes pulldown menus to be activated from which the various system options can be selected.

The screenshot shows a software window with a menu bar at the top containing the following items: **TestSite**, **Event**, **Waveforms**, **Save**, **Help**, and **Quit**. An arrow labeled 'A' points to the 'TestSite' menu item. Below the menu bar is a data entry form with the following labels and corresponding input fields:

Test Site:	
Event Name:	
Origin Date:	
Origin Time(UT):	
Latitude:	
Longitude:	
Depth(km):	
mb:	
Ms:	
Author:	
Comment:	

An arrow labeled 'B' points to the 'Test Site:' label.

A - menu buttons

B - origin data

Test Site

TestSite
Shagan River
Novaya Zemlya

The TEST SITE menu button is used to identify the nuclear test site (Shagan River or Novaya Zemlya) at which the explosion associated with the new data was detonated. A selection must first be made from this menu before making any other selections. The name of the selected test site will then be automatically inserted into the first line of the event parameter template.

Event

Event
Find ...
New
Edit
Accept

The EVENT menu button provides access to several alternate procedures for specifying the explosion which was the source of the new data.

Find

This option is used in situations in which the new seismic data is associated with an explosion which is already in the YES database. Selection of this menu button activates a pop-up window listing the events which are currently in the YES database for the specified test site. If one of these corresponds to the source of the new seismic data, it can be selected with the mouse. Selection of the *OK* button at the bottom of this window will then result in the source parameters for the selected event being automatically transferred to the main menu template. Alternately, if the event of interest does not appear on this list, the analyst can select the *Cancel* button at the bottom of the window to return to the main menu.



A - Click here to select an event.

New

This menu option is selected in cases in which the explosion corresponding to the new date is not in the existing YES database. Following selection of this option, the operator should move the cursor into the area

adjacent to a listed parameter name in the template, click once with the mouse and type the required information. The cursor can then be moved to the next parameter name in the list and the process repeated. Origin Date, Origin Time (UT), Latitude and Longitude are required information; other fields are optional. Origin Date should be entered in the following month/day/year format: 6/20/89. Origin Time (UT) should be entered in the following format: 01:12:22.7. Latitude (Longitude) should be entered in decimal degrees in the following format: 50.036(79.010).

Edit

This menu option is used to modify an event parameter file obtained using the *Find* option described above. That is, if updated values of any of the explosion parameters are available, they can be substituted for the existing values using this function. Following selection of *Edit*, the operator simply moves the cursor to the first character of the field to be replaced, clicks once with the mouse and types in the revised value. This process of positioning the cursor, clicking the mouse and typing values can be repeated until the event parameter file is completely updated.

Accept

Once the event parameter file for the explosion of interest has been finalized, an origin file corresponding to it can be added to the system by selecting the *Accept* menu option. This will cause a new or modified event origin file to be added to the *Find* event list for that test site and to the YES main menu event list on subsequent executions of the YES program. Thus, this module can be used to update existing origin files or add new ones to YES, independent of whether or not new seismic data is added at the same time.

Waveforms

Waveforms
Read Wfdisc File...

Selection of this menu button activates a pop-up window which is used to enter the name of the directory which was created to contain the raw waveform and wfdisc files for the new event, as well as the name of the

wfdisc file within that directory. To enter the name of the directory, simply move the cursor into the box adjacent to the line entitled *Dir:*, click once with the mouse and type in the name which was assigned to that directory when it was originally created. Repeat the same procedure to enter the wfdisc file name on the next line, again using the originally assigned file name. Once these directory and file names have been verified, the operator can select the *OK* button at the bottom of this window to write this information to a temporary file.

Enter directory name containing waveform files
and wfdisc file name.

WFPATH: users \geop \YieldSys \data \seismic

Dir: A

Wfdisc file name: B

OK

A - Enter directory name here.

B - Enter wfdisc file name here.

Save

Save

Save to Database

Once the new explosion parameters and associated waveform directory have been specified using the procedures described above, the new data can be automatically added to the YES database by selecting the **SAVE** button. This initiates a process which will run for about 5 minutes to update all the pertinent database tables and waveform files in YES. These new data will then become available for the analyst to process on all subsequent restarts of the YES system.

Prof. Thomas Ahrens
Seismological Lab, 252-21
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Keiiti Aki
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Prof. Shelton Alexander
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Prof. Charles B. Archambeau
CIRES
University of Colorado
Boulder, CO 80309

Dr. Thomas C. Bache, Jr.
Science Applications Int'l Corp.
10260 Campus Point Drive
San Diego, CA 92121 (2 copies)

Prof. Muawia Barazangi
Institute for the Study of the Continent
Cornell University
Ithaca, NY 14853

Dr. Jeff Barker
Department of Geological Sciences
State University of New York
at Binghamton
Vestal, NY 13901

Dr. Douglas R. Baumgardt
ENSCO, Inc
5400 Port Royal Road
Springfield, VA 22151-2388

Dr. Susan Beck
Department of Geosciences
Building #77
University of Arizona
Tucson, AZ 85721

Dr. T.J. Bennett
S-CUBED
A Division of Maxwell Laboratories
11800 Sunrise Valley Drive, Suite 1212
Reston, VA 22091

Dr. Robert Blandford
AFTAC/TT, Center for Seismic Studies
1300 North 17th Street
Suite 1450
Arlington, VA 22209-2308

Dr. Stephen Bratt
ARPA/NMRO
3701 North Fairfax Drive
Arlington, VA 22203-1714

Dr. Lawrence Burdick
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Robert Burrige
Schlumberger-Doll Research Center
Old Quarry Road
Ridgefield, CT 06877

Dr. Jerry Carter
Center for Seismic Studies
1300 North 17th Street
Suite 1450
Arlington, VA 22209-2308

Dr. Eric Chael
Division 9241
Sandia Laboratory
Albuquerque, NM 87185

Dr. Martin Chapman
Department of Geological Sciences
Virginia Polytechnical Institute
21044 Derring Hall
Blacksburg, VA 24061

Prof. Vernon F. Cormier
Department of Geology & Geophysics
U-45, Room 207
University of Connecticut
Storrs, CT 06268

Prof. Steven Day
Department of Geological Sciences
San Diego State University
San Diego, CA 92182

Marvin Denny
U.S. Department of Energy
Office of Arms Control
Washington, DC 20585

Dr. Zoltan Der
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151-2388

Prof. Adam Dziewonski
Hoffman Laboratory, Harvard University
Dept. of Earth Atmos. & Planetary Sciences
20 Oxford Street
Cambridge, MA 02138

Prof. John Ebel
Department of Geology & Geophysics
Boston College
Chestnut Hill, MA 02167

Eric Fielding
SNEE Hall
INSTOC
Cornell University
Ithaca, NY 14853

Dr. Mark D. Fisk
Mission Research Corporation
735 State Street
P.O. Drawer 719
Santa Barbara, CA 93102

Prof Stanley Flatte
Applied Sciences Building
University of California, Santa Cruz
Santa Cruz, CA 95064

Dr. John Foley
NER-Geo Sciences
1100 Crown Colony Drive
Quincy, MA 02169

Prof. Donald Forsyth
Department of Geological Sciences
Brown University
Providence, RI 02912

Dr. Art Frankel
U.S. Geological Survey
922 National Center
Reston, VA 22092

Dr. Cliff Frolich
Institute of Geophysics
8701 North Mopac
Austin, TX 78759

Dr. Holly Given
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dr. Jeffrey W. Given
SAIC
10260 Campus Point Drive
San Diego, CA 92121

Dr. Dale Glover
Defense Intelligence Agency
ATTN: ODT-1B
Washington, DC 20301

Dan N. Hagedon
Pacific Northwest Laboratories
Battelle Boulevard
Richland, WA 99352

Dr. James Hannon
Lawrence Livermore National Laboratory
P.O. Box 808
L-205
Livermore, CA 94550

Prof. David G. Harkrider
Seismological Laboratory
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Danny Harvey
CIRES
University of Colorado
Boulder, CO 80309

Prof. Donald V. Helmberger
Seismological Laboratory
Division of Geological & Planetary Sciences
California Institute of Technology
Pasadena, CA 91125

Prof. Eugene Herrin
Institute for the Study of Earth and Man
Geophysical Laboratory
Southern Methodist University
Dallas, TX 75275

Prof. Robert B. Herrmann
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Prof. Lane R. Johnson
Seismographic Station
University of California
Berkeley, CA 94720

Prof. Thomas H. Jordan
Department of Earth, Atmospheric &
Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

Prof. Alan Kafka
Department of Geology & Geophysics
Boston College
Chestnut Hill, MA 02167

Robert C. Kemerait
ENSCO, Inc.
445 Pineda Court
Melbourne, FL 32940

Dr. Karl Koch
Institute for the Study of Earth and Man
Geophysical Laboratory
Southern Methodist University
Dallas, Tx 75275

Dr. Max Koontz
U.S. Dept. of Energy/DP 5
Forrestal Building
1000 Independence Avenue
Washington, DC 20585

Dr. Richard LaCoss
MIT Lincoln Laboratory, M-200B
P.O. Box 73
Lexington, MA 02173-0073

Dr. Fred K. Lamb
University of Illinois at Urbana-Champaign
Department of Physics
1110 West Green Street
Urbana, IL 61801

Prof. Charles A. Langston
Geosciences Department
403 Deike Building
The Pennsylvania State University
University Park, PA 16802

Jim Lawson, Chief Geophysicist
Oklahoma Geological Survey
Oklahoma Geophysical Observatory
P.O. Box 8
Leonard, OK 74043-0008

Prof. Thorne Lay
Institute of Tectonics
Earth Science Board
University of California, Santa Cruz
Santa Cruz, CA 95064

Dr. William Leith
U.S. Geological Survey
Mail Stop 928
Reston, VA 22092

Mr. James F. Lewkowicz
Phillips Laboratory/GPEH
29 Randolph Road
Hanscom AFB, MA 01731-3010(2 copies)

Mr. Alfred Lieberman
ACDA/VI-OA State Department Building
Room 5726
320-21st Street, NW
Washington, DC 20451

Prof. L. Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, GA 30332

Dr. Randolph Martin, III
New England Research, Inc.
76 Olcott Drive
White River Junction, VT 05001

Dr. Robert Masse
Denver Federal Building
Box 25046, Mail Stop 967
Denver, CO 80225

Dr. Gary McCartor
Department of Physics
Southern Methodist University
Dallas, TX 75275

Prof. Thomas V. McEvilly
Seismographic Station
University of California
Berkeley, CA 94720

Dr. Art McGarr
U.S. Geological Survey
Mail Stop 977
U.S. Geological Survey
Menlo Park, CA 94025

Dr. Keith L. McLaughlin
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Stephen Miller & Dr. Alexander Florence
SRI International
333 Ravenswood Avenue
Box AF 116
Menlo Park, CA 94025-3493

Prof. Bernard Minster
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Prof. Brian J. Mitchell
Department of Earth & Atmospheric Sciences
St. Louis University
St. Louis, MO 63156

Mr. Jack Murphy
S-CUBED
A Division of Maxwell Laboratory
11800 Sunrise Valley Drive, Suite 1212
Reston, VA 22091 (2 Copies)

Dr. Keith K. Nakanishi
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Prof. John A. Orcutt
IGPP, A-025
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, CA 92093

Prof. Jeffrey Park
Kline Geology Laboratory
P.O. Box 6666
New Haven, CT 06511-8130

Dr. Howard Patton
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Dr. Frank Pilotte
HQ AFTAC/TT
130 South Highway A1A
Patrick AFB, FL 32925-3002

Dr. Jay J. Pulli
Radix Systems, Inc.
201 Perry Parkway
Gaithersburg, MD 20877

Dr. Robert Reinke
ATTN: FCTVTD
Field Command
Defense Nuclear Agency
Kirtland AFB, NM 87115

Prof. Paul G. Richards
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Mr. Wilmer Rivers
Teledyne Geotech
314 Montgomery Street
Alexandria, VA 22314

Dr. Alan S. Ryall, Jr.
ARPA/NMRO
3701 North Fairfax Drive
Arlington, VA 22209-1714

Dr. Richard Sailor
TASC, Inc.
55 Walkers Brook Drive
Reading, MA 01867

Prof. Charles G. Sammis
Center for Earth Sciences
University of Southern California
University Park
Los Angeles, CA 90089-0741

Prof. Christopher H. Scholz
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Dr. Susan Schwartz
Institute of Tectonics
1156 High Street
Santa Cruz, CA 95064

Secretary of the Air Force
(SAFRD)
Washington, DC 20330

Office of the Secretary of Defense
DDR&E
Washington, DC 20330

Thomas J. Sereno, Jr.
Science Application Int'l Corp.
10260 Campus Point Drive
San Diego, CA 92121

Dr. Michael Shore
Defense Nuclear Agency/SPSS
6801 Telegraph Road
Alexandria, VA 22310

Dr. Robert Shumway
University of California Davis
Division of Statistics
Davis, CA 95616

Dr. Matthew Sibol
Virginia Tech
Seismological Observatory
4044 Derring Hall
Blacksburg, VA 24061-0420

Prof. David G. Simpson
IRIS, Inc.
1616 North Fort Myer Drive
Suite 1050
Arlington, VA 22209

Donald L. Springer
Lawrence Livermore National Laboratory
L-025
P.O. Box 808
Livermore, CA 94550

Dr. Jeffrey Stevens
S-CUBED
A Division of Maxwell Laboratory
P.O. Box 1620
La Jolla, CA 92038-1620

Lt. Col. Jim Stobie
ATTN: AFOSR/NL
110 Duncan Avenue
Bolling AFB
Washington, DC 20332-0001

Prof. Brian Stump
Institute for the Study of Earth & Man
Geophysical Laboratory
Southern Methodist University
Dallas, TX 75275

Prof. Jeremiah Sullivan
University of Illinois at Urbana-Champaign
Department of Physics
1110 West Green Street
Urbana, IL 61801

Prof. L. Sykes
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964

Dr. David Taylor
ENSCO, Inc.
445 Pineda Court
Melbourne, FL 32940

Dr. Steven R. Taylor
Los Alamos National Laboratory
P.O. Box 1663
Mail Stop C335
Los Alamos, NM 87545

Prof. Clifford Thurber
University of Wisconsin-Madison
Department of Geology & Geophysics
1215 West Dayton Street
Madison, WI 53706

Prof. M. Nafi Toksoz
Earth Resources Lab
Massachusetts Institute of Technology
42 Carleton Street
Cambridge, MA 02142

Dr. Larry Turnbull
CIA-OSWR/NED
Washington, DC 20505

Dr. Gregory van der Vink
IRIS, Inc.
1616 North Fort Myer Drive
Suite 1050
Arlington, VA 22209

Dr. Karl Veith
EG&G
5211 Auth Road
Suite 240
Suitland, MD 20746

Prof. Terry C. Wallace
Department of Geosciences
Building #77
University of Arizona
Tucson, AZ 85721

Dr. Thomas Weaver
Los Alamos National Laboratory
P.O. Box 1663
Mail Stop C335
Los Alamos, NM 87545

Dr. William Wortman
Mission Research Corporation
8560 Cinderbed Road
Suite 700
Newington, VA 22122

Prof. Francis T. Wu
Department of Geological Sciences
State University of New York
at Binghamton
Vestal, NY 13901

ARPA, OASB/Library
3701 North Fairfax Drive
Arlington, VA 22203-1714

HQ DNA
ATTN: Technical Library
Washington, DC 20305

Defense Intelligence Agency
Directorate for Scientific & Technical Intelligence
ATTN: DTIB
Washington, DC 20340-6158

Defense Technical Information Center
Cameron Station
Alexandria, VA 22314 (2 Copies)

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201 (Final Report)

Phillips Laboratory
ATTN: XPG
29 Randolph Road
Hanscom AFB, MA 01731-3010

Phillips Laboratory
ATTN: GPE
29 Randolph Road
Hanscom AFB, MA 01731-3010

Phillips Laboratory
ATTN: TSML
5 Wright Street
Hanscom AFB, MA 01731-3004

Phillips Laboratory
ATTN: PL/SUL
3550 Aberdeen Ave SE
Kirtland, NM 87117-5776 (2 copies)

Dr. Michel Bouchon
I.R.I.G.M.-B.P. 68
38402 St. Martin D'Herès
Cedex, FRANCE

Dr. Michel Campillo
Observatoire de Grenoble
I.R.I.G.M.-B.P. 53
38041 Grenoble, FRANCE

Dr. Kin Yip Chun
Geophysics Division
Physics Department
University of Toronto
Ontario, CANADA

Prof. Hans-Peter Harjes
Institute for Geophysics
Ruhr University/Bochum
P.O. Box 102148
4630 Bochum 1, GERMANY

Prof. Eystein Husebye
NTNF/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY

David Jepsen
Acting Head, Nuclear Monitoring Section
Bureau of Mineral Resources
Geology and Geophysics
G.P.O. Box 378, Canberra, AUSTRALIA

Ms. Eva Johannisson
Senior Research Officer
FOA
S-172 90 Sundbyberg, SWEDEN

Dr. Peter Marshall
Procurement Executive
Ministry of Defense
Blacknest, Brimpton
Reading FG7-FRS, UNITED KINGDOM

Dr. Bernard Massinon, Dr. Pierre Mechler
Societe Radiomana
27 rue Claude Bernard
75005 Paris, FRANCE (2 Copies)

Dr. Svein Mykkeltveit
NTNT/NORSAR
P.O. Box 51
N-2007 Kjeller, NORWAY (3 Copies)

Prof. Keith Priestley
University of Cambridge
Bullard Labs, Dept. of Earth Sciences
Madingley Rise, Madingley Road
Cambridge CB3 0EZ, ENGLAND

Dr. Jorg Schlittenhardt
Federal Institute for Geosciences & Nat'l Res.
Postfach 510153
D-30631 Hannover , GERMANY

Dr. Johannes Schweitzer
Institute of Geophysics
Ruhr University/Bochum
P.O. Box 1102148
4360 Bochum 1, GERMANY

Trust & Verify
VERTIC
8 John Adam Street
London WC2N 6EZ, ENGLAND